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UNRESTRICTED

MENTAL PRACTICE

and

MOTOR LEARNING

#####

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Thesis submitted to The Open University for the degree
of Master Of Philosophy, (Re-submitted 1987).

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SUMMARY

This thesis is an investigation into the phenomena of mental practice, that is the thinking through of a movement, or movement sequences prior to actual performance. Using a gross motor skill it was demonstrated that it is the sequential, or cognitive component of the task that is most affected by mental practice, rather than the execution of the movements themselves.

As a result of enhanced sequence learning overall performance does improve. Further experiments revealed that individuals can produce novel movement sequences without prior physical practice of the task. Subjects demonstrated the ability to produce such sequences as long as they have information about the order and types of movements to be performed.

Finally, an attempt was made to characterise the individual differences that might be associated with the capacity to use mental practice effectively. The literature on mental practice reveals that imagery may be a factor within this context. A test of imagery was designed, and its validity and reliability established. This test was used to screen subjects prior to participation in a mental practice study. Unfortunately, no significant relationship was found between imagery, as measured by the test, and improved performance on the task. There was however, a correlation between test scores and the rate of initial learning.

The experimental results are discussed in terms of two proposals. The first is the relationship between mental practice and symbolic learning theory. The second is the possible role of such practice in the preparation of motor programs prior to performance.

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CONTENTS

	PAGE NUMBER
CHAPTER ONE	
THEORIES OF MOTOR CONTROL	1 - 20
INTRODUCTION	1 - 2
THEORIES OF MOTOR CONTROL	3 - 10
Closed Loop Theories Of Motor Learning	5 - 6
Problems With Closed Loop Models	7 - 76
VOLUNTARY MOVEMENT IN THE ABSENCE OF	
PROPRIOCEPTION	7 - 8
The Problems Of Storage And Novel Movement	9 - 9
Open Loop Models Of Motor Learning	10 - 12
Problems With Open Loop Models Of Motor Control	12 - 13
ORGANISATION OF THE UNITS OF MOVEMENT BEHAVIOUR	13 - 17
Motor Control An The Type Of Skill	17 - 18
MOTOR CONTROL AND THE AIMS OF THE PRESENT STUDIES	18 - 20
SUMMARY	20 - 20
CHAPTER TWO	
MENTAL PRACTICE AN OVERVIEW	21 -43
INTRODUCTION	21 - 22
The Mental Practice Paradigm	22 - 24
EXPLANATIONS OF MENTAL PRACTICE	25 - 33
The Neuromuscular Hypothesis Of Mental Practice	25 - 27
Motor Programs And Mental Practice	27 - 29
The Symbolic Learning Hypothesis	29 - 33
VARIABLES MANIPULATED IN MENTAL PRACTICE STUDIES	33 - 41
Time Of Mental Practice	33 - 35
Mental Practice And Type Of Skill	35 - 36
Mental Practice And Task Difficulty	36 - 37
Schedules Of Mental Practice	37 - 39
Subjective Organisation And Mental Practice	39 - 39
Mental Practice And Knowledge Of Results	40 - 41
SUMMARY	42 - 43

CHAPTER THREE	
MENTAL PRACTICE AND INTERACTIVE SKILLS	44 - 67
EXPERIMENT ONE	44 - 51
Method	47 - 48
Results	48 - 50
Discussion	51 - 51
The Runway	51 - 52
EXPERIMENT TWO	52 - 62
Introduction	52 - 54
Method	54 - 56
Results	56 - 58
Discussion	58 - 62
EXPERIMENT THREE	62 - 67
Introduction	62 - 62
Method	63 - 64
Results	64 - 65
Discussion	65 - 67
CHAPTER FOUR	68 82
IMAGERY AND MENTAL PRACTICE	
Introduction	68 - 70
Imagery and Mental Practice	70 - 77
EXPERIMENT FOUR	77 - 82
Method	78 - 79
Results	79 - 80
Discussion	80 - 82
CHAPTER FIVE	83 - 93
CONCLUSIONS	
Introduction	83 - 83
MENTAL PRACTICE AND THE SYMBOLIC LEARNING	
HYPOTHESIS	83 - 86

MENTAL PRACTICE AND MOTOR PROGRAMS	85 - 86
SIMPLE ACQUISITION OF THE RUNWAY TASK	86 - 90
The Cognitive Stage	87 - 88
The Associative Stage	88 - 90
SEQUENCE REVERSAL ON THE RUNWAY TASK	90 - 92
FUTURE DIRECTIONS AND APPLICATIONS	92 - 93

CHAPTER ONE

THEORIES OF MOTOR CONTROL

	PAGE NUMBER
INTRODUCTION	1 - 2
THEORIES OF MOTOR CONTROL	3 - 10
Closed Loop Theories Of Motor Learning	5 - 6
Problems With Closed Loop Models	7 - 76
VOLUNTARY MOVEMENT IN THE ABSENCE OF PROPRIOCEPTION	7 - 8
The Problems Of Storage And Novel Movement	9 - 9
Open Loop Models Of Motor Learning	10 - 12
Problems With Open Loop Models Of Motor Control	12 - 13
ORGANISATION OF THE UNITS OF MOVEMENT BEHAVIOUR	13 - 17
Motor Control An The Type Of Skill	17 - 18
MOTOR CONTROL AND THE AIMS OF THE PRESENT STUDIES	18 - 20
SUMMARY	20 - 20

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INTRODUCTION

Recent trends in the study of movement skills have emphasised the cognitive activities of the learner. Just as individuals can perform mental arithmetic, so too can they engage in 'mental movement', to solve a problem, or gain a new skill. The motor aspects of action are the articulation of the skeleton by the contraction of muscles, however, such activity is only a small part of the movement production system. Other processes also play an essential role in skilled performance, these include the selection and planning of actions. Prior to planning the learner must have knowledge about both the environment and the goal to be achieved. Reference will then be made to a long-term memory store which contains the general characteristics of the individual's past movement experiences. This information is constantly being updated and reorganised as new data about the relationships between actions and outcomes are acquired through experience.

Once the individual has knowledge about the conditions in which performance is demanded, a novel movement instance, or motor program will be generated which selects the specific actions necessary to achieve the desired goal. This information is thought to be represented at its highest level in the form of 'cognitive entities', or movement plans, and it might be reasonable to assume that such entities can be manipulated by purely psychological processes which do not necessarily involve concomitant muscular activity. Although behaviourally silent at the time of acquisition, the effect of such cognitive manipulation may well be manifest in subsequent

performance. The present studies are an attempt to influence these cognitive processes using mental practice to manipulate and restructure motor information which is held at the highest level within the movement production system.

In order to appreciate the role of mental practice in the context of skill acquisition it will be necessary to briefly examine the theories of motor control. The literature on mental practice is examined together with comments and criticisms. This examination reveals that many previous studies of mental practice have been conducted in a theoretical vacuum. In Chapter Two a particular theoretical stance is adopted, and the problems of experimental procedures are discussed. The rationale for the experimental paradigm adopted is discussed and the apparatus design is described. In Chapter Three the mental practice effect is established and an attempt is made to isolate those aspects of skill learning which are susceptible to such practice. The remainder of the thesis is devoted to the study of individual differences and mental practice. The possibility is considered that imagery ability may be positively related to the mental practice effect, and this hypothesis is tested experimentally using a novel test of imagery. Finally, there is a statement of the conclusions that may be drawn from this work.

THEORIES OF MOTOR CONTROL

The expression of skilled movement is demonstrated by all individuals throughout daily life. In order to produce skilled movements, muscles must be activated and coordinated by commands from the sensory-motor cortex. Traditionally, there are two theoretical approaches which have attempted to explain the production and performance of complex movement sequences. The first assumes that movement is dependent on sensory feedback for both control, and the detection and correction of errors, whereas the second argues that movement is programmed centrally and can be executed without reference to peripheral information. The fundamental question is how do these two approaches differ in their explanation of movement control and the acquisition of skills. For the sake of clarity, a distinction must be made between the mechanisms which control movement, and the processes which underlie the acquisition of movement. The control of movement can be studied without reference to learning, however, learning cannot be accounted for without consideration of the mechanisms which control movements.

Theories which are based on the notion that motor responses are feedback dependant are known as closed loop models of motor control. The sensory consequences of the movement returns to higher centres to be compared to an internal reference, in order to detect errors and correct them on future trials. This internal reference of correctness is thought to be an abstract image of the feedback associated with the appropriate movement. Once this internal standard is

established, it guides responding and detects errors which will be corrected during subsequent attempts. Thus learning occurs as a result of the performer's increasing ability to update and use the internal reference as a checking mechanism for the sensory consequences of each performance.

By contrast to this closed loop model is the open loop system where movement is not thought to be under constant monitoring, but rather directly controlled by central mechanisms. This approach to motor control assumes that movements are pre-programmed, and furthermore, that such programs contain all the information necessary to perform the movement. The open loop system is somewhat analogous to a computer system where programs can be run-off without reference to peripheral mechanisms. In this case, learning can occur, either as a result of stimulus response contiguity, or the development of motor schema which are based on past movement experience. If errors occur this information is passed back to a central mechanism where two options are possible, first the goal of the movement can be changed, or second a particular response can be discarded, and new associations can be formed so as to mediate a more appropriate response. These two approaches to the control and learning of movements have been introduced in terms of response production. Owing to the complexities of human motor skills, however, it is essential that the way in which responses are organised into meaningful sequences should also be considered.

The following is an attempt to present the reader with an overview of the theories which have sought to explain motor control with specific reference to learning, and consideration

will be given to closed and open loop models of control in this context. It will be apparent that the nature of the skill itself will require analysis, as it may be a critical factor in determining which system of control meets the demands of the task to be performed. Finally, the discussion will focus on the way in which the control of movement production is organised. The various modes of organisation will be assessed in order to justify the aims of the present studies. The proposal is that, whatever method of organisation is imposed upon responding, it is the sequencing of these responses which represents one of the highest levels within the mechanism that controls the production of complex movement patterns. If mental manipulation of this cognitive component of skilled learning results in the improvement of subsequent performance, then specific practice of this element, or mental practice, may play a crucial role in the acquisition of complex motor skills. This proposal will then be related to the various modes of organisation that can be imposed on response production.

Closed Loop Theories Of Motor Learning

Historically, motor learning has evolved within a behaviourist perspective. Thorndike's Law Of Effect simply states that, if a response is followed by a reward this will lead to a repetition of that response, and punishment will lead to the elimination of that response. The rules that accompany the Law Of Effect, however, do not always hold true for human motor learning. The technique of a highly skilled performer, will not disappear simply because reinforcement is either

delayed or withdrawn, which is what would be predicted by a naive interpretation of Thorndike's Law. In 1971 Adams proposed a closed loop theory of motor learning in an attempt to overcome this, and other problems that have been associated with the traditional S-R theories of learning.

Adam's theory has two distinct features, a perceptual trace which controls and monitors movement production, and a memory trace which is responsible for the initiation of the movement and functions essentially like an S-R association. Once the response has started, however, the movement becomes independent of the triggering stimulus and is controlled by reference to the perceptual trace. This trace acts as a reference against which feedback stimuli from the response can be compared. The perceptual trace is made up of the sensory consequence occurring at the completion of the most recent successful response, and the trace will be strengthened the more times the subject performs this response. If an error should occur the subject will, using knowledge of results, ensure that his next response differs from the previous one, so its feedback will not match the trace associated with the incorrect response. The comparison between the current state of feedback from the ongoing response, and the perceptual trace of the correct response control the form and termination of the action in progress. Adams proposed that during early learning subjects rely heavily on knowledge of results and verbal mediation, and his model is clearly dependent upon sensory information for both the formation of the trace and the evaluation of performance during execution.

Problems With The Closed Loop Model Of Motor Learning

One of the problems with a feedback dependent model, such as Adams, is that it has difficulty in accounting for movement in the absence of proprioception. One aspect of this difficulty is the delay inherent in the proprioceptive feedback loop. Information cannot reach control centres fast enough to modify a response in progress. Many actions, particularly the rapid movements often produced by skilled performers, occur faster than the delay inherent in this system (about 200 msec.). This rate limiting factor has been one of the stumbling blocks in all closed loop theories of motor control,

Recent physiological studies have provided evidence that may afford a solution to this problem. Such studies have revealed that there may be not one, but two feedback loops which carry proprioceptive information. The first, a short fast loop, the second a slow loop. To account for rapid movements in terms of a closed loop model, it is argued that there is a closed loop reflexive mechanism in the limbs which involves the gamma loop and muscle spindle which operates to correct errors during the performance of rapid movements.

Voluntary Movement In The Absence Of Proprioceptive Information

Lashley (1917), in his classic study of a patient with spinal damage demonstrated that despite the absence of sensory feedback from the moving limbs his patient could still make voluntary movements with that limb, and furthermore, reproduce movements that had previously been passively placed. More recently, Taub and Berman (1968) have provided further support

X for Lashley's findings. Using deafferented monkeys they demonstrated that purposeful and coordinated gross body movement could be made in the absence of sensory feedback. Fine ~~discreet~~ movements, however, such as picking up small objects did show some deficits. Taub states that, "once a motor program is written into the CNS the specified behaviour having been initiated can be performed without any reference to guidance from the periphery, moreover, there does not appear to be any reason why the initiation, the trigger cannot also be wholly central in nature". Other evidence to support this centralised view of motor control comes from ethological studies of so-called fixed actions patterns; for example, swallowing in vertebrates, which is known to be independent of peripheral control (Hinde 1970).

The general conclusion from the deafferentation studies is that certain skilled voluntary movement can be made independently of proprioceptive information which presents problems for the closed loop, or feedback dependent models. Theorists such as Adams have attempted to defend their position, their most obvious criticism being that though proprioception may be absent, other senses, such as vision, are intact and able to guide responding. Taub and Berman (1968), however, have shown that competent performance does occur even when the monkeys were deprived not only of proprioception, but also vision. Of course, there are still other sensory channels which could pass on information, although it is generally agreed that vision and proprioception are critical to movement production.

The Problem Of Storage And Novel Movement

Even if we accept that closed loop control is possible, either in the absence of proprioceptive information, or with attenuation of such information, how can a closed loop model account for the production of a novel movement? In the closed loop system there must be an internal reference of correctness to which the sensory consequences of a movement can be compared. Therefore, if the individual produces a movement which achieves his goal, it is assumed he has an internal standard against which to compare performance, and if this is the case every movement will require an appropriate stored perceptual trace. This would seem to impose an excessive burden on memorial processes, especially on those engaged in monitoring current movement. Furthermore, it is difficult to see how novel movements could be made if there is no standard existent, against which the individual can compare performance. Because according to a closed loop theory a standard can only be established through prior experience of the movement.

The storage problem could be overcome by postulating that the recall of movement information is a 'constructive' process and moreover, of a more general nature, rather than specific traces for particular movements. Once the performer is given knowledge about the environment and the goal, he can actively recall the most appropriate movements within a response class and execute them to achieve the desired goal. Such a proposal would allow the individual to produce novel movements that are successful. Closed loop theories, however, say little about such a constructive memorial process.

Response Initiation

In feedback dependent models of motor learning sensory information guides responding once the movement is under way, however, what is the trigger, or stimulus for initiating the response? Adams suggests that through stimulus-response pairings a second trace is formed which is known as the memory trace, and this is strengthened over trials through practice. The function of this memory trace is not to control the movement, but to initiate and select the first response. Adam's theory has two distinct memory states; the memory trace, which is dependent on motor recall, and the perceptual trace which is dependent on recognition to guide the movement.

Open Loop Models Of Motor Learning

One feature of the open loop models of motor learning is that the monitoring of movement during execution is not always necessary. Both Lashley (1917) and Woodworth (1899), entertained the concept of a motor program in the form of a pre-structured unit, or program of a generalised nature which could be 'run off' automatically, without reference to peripheral mechanisms. Since these early ideas on the programmed control of motor performance, the concept has been expanded and refined. This is in part due to the recent influence of artificial intelligence models used to describe human behaviour.

Fitts and Posner (1967), two of the early researchers, suggested the analogy between movement control and a computer system. It is clear that simple movements might be similar to

a program within a computer, moreover, there is no reason to suppose that such programs, in the form of sub-units, could not be structured and linked in such a way as to form more complex programs which would be analogous to a movement sequence. Keel (as reported in Schmidt 1982) proposed a Gearshift Analogy to explain how programs might be combined to produce a complex movement sequence. During initial learning each action is thought to be controlled by a single program, with practice the first two elements combine and become controlled by a single program, this is followed by the combination of three components. So as practice continues all components will be combined and controlled under the auspices of a single program. Such motor control programs are thought to be of a generalised nature, to which caveats can be added, in order to execute a specific movement, in a particular circumstance. These parameters might include such details as, force or speed of movement.

Open loop models are often looked upon with some scepticism as there is little evidence from human experimental studies to substantiate such a theory. There are data from sub-human species however, which support this centralist view; for example, locust flight (Wilson 1964) and bird song (Nottebohm 1970). Wilson, in his studies of locust flight, demonstrated that removal of the wings of the locust did not affect the movement patterning of the exposed muscle endings. To decrease any other sensory information, Wilson not only removed the wings, but also the legs and body, thus leaving only the head. The remaining projections, which would have normally carried information to the wings, still showed the

normal flight pattern. Wilson concluded from these studies that there must be a central program for wing movements in the locust.

Problems With Open Loop Models Of Motor Control

According to the open loop theory of movement control, actions can be executed without reference to peripheral information. If this is the case, then how can the individual modify performance, or detect errors during execution? When an error does occur in performance, this may be for one of two reasons; first that the wrong program has been selected, or second, that although the correct program was chosen initially, some event occurs which disrupts performance. In the first case, a new program must be selected which requires the engagement of higher processes. In the second, the initial program was correct so it can be re-run if the motor system itself can cope with the unexpected event. Furthermore, as there is no need for the selection of a new program, higher centres need not be involved and error correction can occur rapidly. The mechanism which provides a means for this rapid correction of errors is the gamma loop between the contracting muscle and the spinal cord. This functions as a follow-up servo system which can operate without reference to higher processes.

Another difficulty with the pre-programmed notion of motor control is that movements are rarely carried out in exactly the same way; for example, a tennis forehand drive may never be performed in an identical manner. How can this be so if the movement is under the control of a program? This again

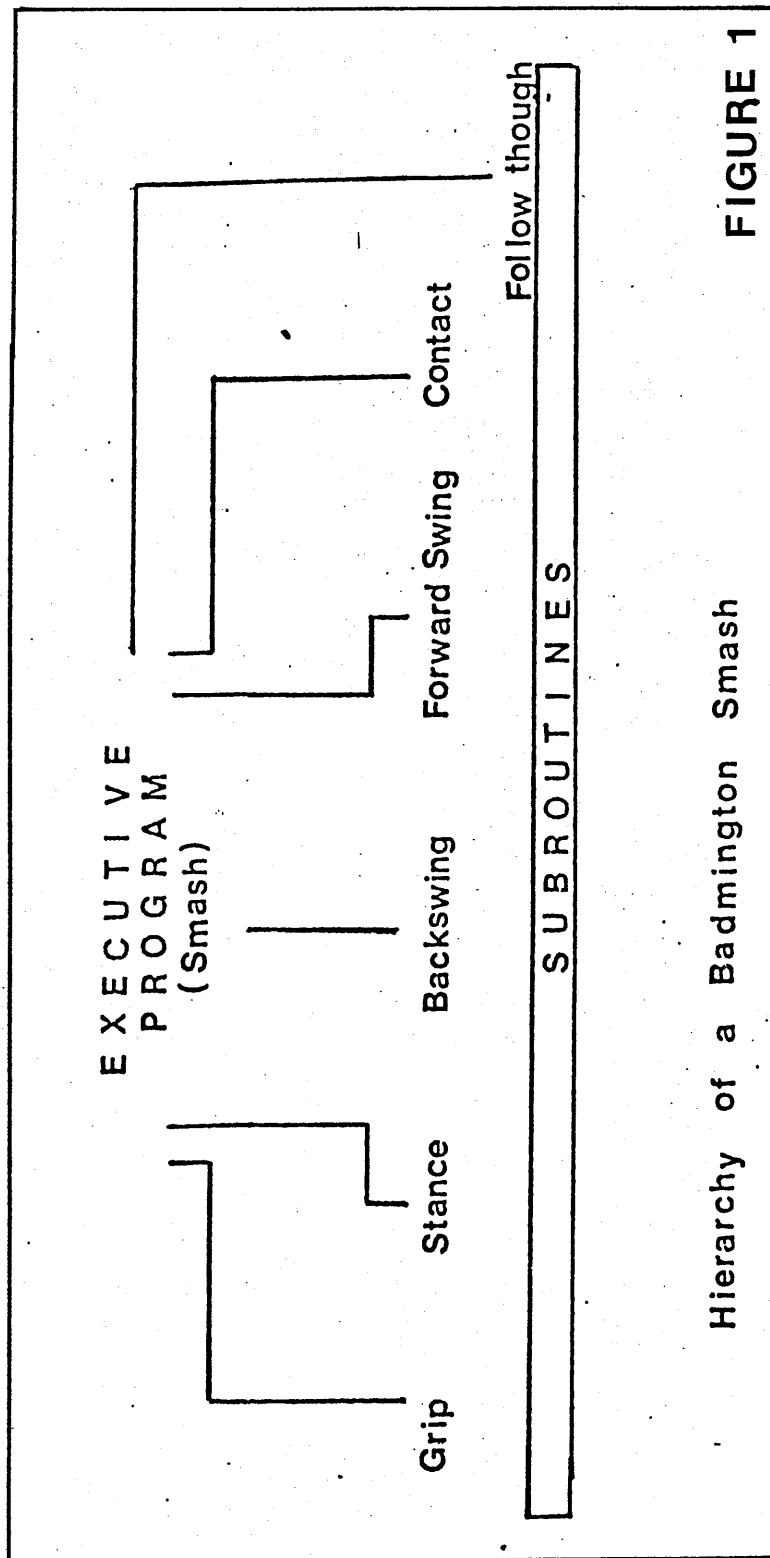
invokes the problem of the production of novel movements. Let us look at the tennis stroke. If studied in detail, no two will be the same, therefore every stroke is in some sense a novel movement. The production of each stroke will be based on what the individual knows about the playing of tennis, and he will be able to select a general program which will produce the type of shot he requires. With the addition of various parameters to the program the individual will be able to execute the specific movement successfully.

Whether we are considering open or close loop models of motor control, some form of feedback is assumed to operate. In the former case feedback forms the basis for a redefinition of goals, or re-selection of responses for the next attempt. In the latter case feedback via the gamma loop maybe responsible for modifying behaviour during movement production. The dependence on some form of feedback in the two different control systems is not disputed, but rather it is the way in which it functions within them that is of interest.

ORGANISATION OF THE UNITS OF MOVEMENT BEHAVIOUR

In this section three principles of the organisation of motor units will be considered; chaining, hierarchies and schemas. Serial chaining is the linking together of S-R units. The feedback consequences of one movement becomes the stimulus for the next movement, and so on, to form a chain of S-R connections. One difficulty with the notion of chaining comes from studies that have shown performance of movement sequences in the absence of proprioception however, once

FIGURE 1. Hierarchy of a badminton smash.



Hierarchy of a Badminton Smash

FIGURE 1

proprioception is removed, the chain is broken and the movement sequence becomes disrupted.

The second type of organisation is that of a hierarchy as proposed by Fitts and Posner (1967), and Bryan and Harter (1899). The notion of hierarchical control is analogous to the control of language processes (Chomsky 1972). This may be the reason why movement is often referred to as the language of the body. The deep structure, or goal of the movement is not manifest in the surface structure, or in the individual movements themselves. Consider the hypothetical hierarchy of a badminton smash (Figure One)

When such a hierarchy is fully developed, it would no doubt provide a detailed description of how a successful smash might be accomplished; however, unless it is organised and ordered in some way it becomes merely a collection of descriptive statements. The idea of a hierarchy alone is not enough, as the critical feature is the 'ordering principle', that controls the sequence in which each of the operations is performed. The type of mechanism that might fulfil this role is often referred to as an executive, and is responsible for guiding operations and overseeing the interactions that occur between the operations.

The problem with the hierarchical model of motor control is that the distinctions between each level are not clear, and the information stored within each level uncertain. Possibly some of the most fruitful ways of testing such a model is through the construction of a computer analogy which could be assessed on a succeed or fail criterion. Testing would operate through

the various levels within the hierarchy on the basis of a TOTE unit principle (Miller, Galanter and Pribrum, 1960).

The final mode of organisation that has been applied to motor control is the notion of a schema. Bartlett (1958) used the idea to explain data from his verbal recall experiments which was then generalised to describe motor behaviour in British sport, in this case cricket! Schemas are thought to be rules used by the individual to classify responses into larger units that have similar overall characteristics, thus making the stored information of a more general nature. Schmidt (1957) revived the notion of schema in motor learning and proposed that through past experience the individual forms relationships between how muscles are activated, what muscles do, and how such actions feel. This knowledge provides the individual with rules, or schemas about the way in which his body works.

Schema theory as proposed by Schmidt has two distinct processes, the first a recall schema which initiates the response and corrects errors. This recall schema is based on past experiences of the relationship between actual outcomes and response specifications. So the individual makes a movement and pairs the response specifications with the outcomes of that specific episode. After a number of such experiences a relationship is formed between these two variables and will be updated as new information is acquired. When the individual is required to produce a novel movement he enters the schema with the outcome and the initial conditions specified. The schema relationships produce the response

specifications for that movement, which is then executed by running a motor program.

The second process is a recognition schema which operates to evaluate responses and consists of the relationship between initial conditions, sensory consequences and actual outcomes. During actual movement the individual specifies the outcomes of the movement and predicts, through the recognition schema the sensory consequences of that movement. The actual sensory consequences of the movement are then compared with the expected sensory results, any disparity between the two indicates that an error has occurred. It is clear that once the recognition schema is well established then error correction can be accomplished without knowledge of results. Furthermore, once the actual consequences of the movement are available the recall schema can be updated.

The schema in such a model would be powerful enough to modify, or change the goal of the movement should the individual find that his movement is affected by external perturbations that cannot be handled by peripheral feedback; for example a gust of wind, just as the golfer is about to play a stroke. In this case the program has already been initiated and is therefore uninfluenced by peripheral feedback; however, the motor schema will allow the golfer to modify his goal so correct execution of the movement will occur.

The fundamental principle of schema theory is the motor program. Schemas operate in the context of the motor program which has parameters that determine a specific movement instance. Schmidt proposed that schemas are internal representations of the individual's past movement experience in

the form of multi-mode information which is organised through sensory integration. Schemas then are rules for learning, the claim is that under this system slow movements are feedback based, and rapid movements are program based. With experience the individual develops rules for movement and is then able to generate novel actions based on his past experience with these rules.

Motor Control And The Type Of Skill

The extent to which feedback is important may vary from one skill to another, with the skill itself determining, or at least influencing, the type of system that controls the movements. It is within this context that we shall consider the main divisions of skills, i.e. open and closed. An open skill is one performed in a changing environment and will therefore demand flexibility of execution. It would be reasonable to suppose that open skills are more likely to be feedback dependent, in order to cope with such changes.

The second skill category is a closed skill, where the emphasis is on correct repetition of a set movement pattern. By contrast to the open skill situation the environment of a closed skill remains relatively stable, and it may be that movements are more likely to be pre-programmed. The final factor is the extent to which skills are innate, or learned. Summers and Keele (1976) have suggested that movements with a large innate component are likely to be pre-programmed, whereas feedback monitoring will play a greater role in those skills that must be learned, for example manipulative skills.

The controversy within the literature about the various systems of motor control may, in part, be due to the nature of the skills that were tested. In Adams' case the information on which his theory is based comes largely from experimental data on a ~~discreet~~ and closed skill, in this case a linear positioning task. The problems with Adams' theory and others like it are only revealed when other variables are introduced, or when the theory is generalised to skills of a different type.

Two theoretical approaches to motor control have been considered, and it seems that both the feedback dependent system and the pre-programmed system must, of necessity co-exist, in order to account for the complexity of human motor behaviour. Due to the variety of skills, some which have an innate component, and others which do not, together with the fact that different skills make dissimilar demands on the information processing system, implies that our approach to motor learning should be eclectic. The proposal is that both open and closed loop models of motor control are essential, in order to provide a satisfactory theoretical account of motor learning.

MOTOR CONTROL AND THE AIMS OF THE PRESENT STUDIES

The emphasis in the present programme of study is to examine the organisation of the units of motor behaviour, more specifically, these studies will focus on the ordering of motor events within a sequence, as this appears to be a critical feature in skill acquisition. The organising of movements implies some form of cognitive process at work, whereby

responses can be manipulated into meaningful movement sequences. If, by specific practice of the sequential component of a task, or skill it is possible to facilitate acquisition and furthermore, improve performance, then this would have implications as to how the units of motor behaviour are organised. The types of cognitive processes which might accompany such specific practice would greatly add to our understanding of the principles of organisation which are fundamental to motor learning.

Traditionally skills are thought of as primarily motor in nature, more recently, however, the emphasis has changed in that the cognitive aspects of skill learning are thought to play a vital role in the organisation and control of movement. If mental practice is 'imagined' movement, without actual movement, then such practice may be the mental manipulation of the sequential elements that are responsible for structuring the movements. Alternatively, mental practice could be the mediational process for specifying the various parameters of a planned movement sequence.

Thus this study is an attempt to show that mental practice works by facilitating and organising the cognitive component of a task which guides operations during execution of a movement sequence. The second proposal is that mental practice may be the process by which individuals prepare a program prior to movement execution. Whether these two proposals are separable is at present somewhat in doubt. It is clear, however, that facilitation of the sequential component, and subsequent enhanced levels of performance, following mental practice can be tested experimentally.

Finally, by manipulating this component of the skill and by examining individual differences on a differential basis it is hoped to reveal the nature of the cognitive processes that may accompnay the mental practice phenomena.

SUMMARY

In this introduction the various approaches to motor control and the acquisition of skill have been discussed, and in addition some analysis of the methods by which motor information is organised were considered. The theoretical discussion revealed the necessity to review the nature of skills themselves as this factor may be crucial in determining their method of control. Three types of organisation were considered: chaining, hierarchies and schemas. The common principle that emerged was that all these principles function by imposing order on the events, or movements to be performed, and it is this issue which is the concern of the present investigations.

CHAPTER TWO

MENTAL PRACTICE AN OVERVIEW

	PAGE NUMBER
INTRODUCTION	21 - 22
The Mental Practice Paradigm	22 - 24
EXPLANATIONS OF MENTAL PRACTICE	25 - 33
The Neuromuscular Hypothesis Of Mental Practice	25 - 27
Motor Programs And Mental Practice	27 - 29
The Symbolic Learning Hypothesis	29 - 33
VARIABLES MANIPULATED IN MENTAL PRACTICE	
STUDIES	33 - 41
Time Of Mental Practice	33 - 35
Mental Practice And Type Of Skill	35 - 36
Mental Practice And Task Difficulty	36 - 37
Schedules Of Mental Practice	37 - 39
Subjective Organisation And Mental Practice	39 - 39
Mental Practice And Knowledge Of Results	40 - 41
SUMMARY	42 - 43

MENTAL PRACTICE

AN OVERVIEW

Introduction

Mental practice is the 'imagining of a motor skill without the occurrence of any overt movement'. During the last forty years many investigators have examined the phenomenon of mental practice, which is sometimes referred to as mental rehearsal, covert practice, or internalised rehearsal. Overall, however, the area reflects a confusing array of evidence, together with a lack of any common theoretical approach. The emphasis of the majority of these studies has been on the facilitatory effects of mental rehearsal on motor skills during acquisition, as reflected in improvements of performance. This emphasis is in part due to the fact that mental practice is seen to have advantages as a training method in sport and physical education (Whitehead, 1974. Suinn, 1970).

More recently, investigators have begun to see the value of mental practice as a research tool (Summers, 1977), in that it may provide insights into motor control processes. This change of direction is associated with a similar change of emphasis in theories of motor control and the acquisition of skills. Rather than seeing movement behaviour simply in terms of motor responses, the contemporary view is that such behaviour may be interpreted as a composition of cognitive processes which intervene between stimulus presentation and response generation. Before we embark on an evaluation of the various explanations of mental rehearsal it will be necessary

to consider in general terms the methodology and constraints on the effectiveness of mental practice.

The Mental Practice Paradigm

The usual procedure for studying mental practice involves at least three groups of subjects, a physical practice group, a mental practice group and a control, or no-practice group. Subjects are typically rated for baseline levels of performance before the different treatments begin. In general the physical practice group continues actual performance of the task, with the mental practice group engaging in some form of imaginary practice, while the control group, either do nothing or perform a distractor task to prevent rehearsal of the skill. In this way the effects of mental practice on subsequent performance is assessed and compared to the other methods of treatment.

Rawlings, Chen and Yilk (1972) using the pursuit rotor task demonstrated the mental practice effect. Three groups; physical practice, mental practice and no-practice received 25 trials on day one of the study, and on days 2 to 9 subjects engaged in their various practice methods, depending on the groups to which they were assigned. Practice, both physical and mental was 25 trials per day. All subjects were tested on day 10, by performing a further 25 trials. Results showed that the mental practice group did learn over the treatment period, almost to the extent of the physical practice group. By contrast, the controls improved hardly at all.

It is difficult to assess the rate of learning of the mental practice group as data points are only available for day one

and day 10 of the study, whereas for the physical practice group data points are available for every day of practice. Nevertheless, overall mental practice is shown to be an effective way of facilitating acquisition on the pursuit rotor. These results are somewhat surprising in view of comments made by Smyth (1975), and others who have reported little or no effect of mental practice on this task. Furthermore, many subjects report difficulties in imagining the pursuit rotor task. Smyth says, "subjects should perhaps be taught to practice mentally before being used in experiments of this sort",/ (pursuit rotor). This fact may account for the ineffectiveness of mental practice on the pursuit rotor task. It has also been revealed that massed mental practice trials are difficult to engage in, (Corbine 1972), as concentration is difficult to maintain, so all-in-all the Rawlings et al results should be view with a little scepticism.

What is happening in the mental practice situation? Intuitively, we might suppose that individuals must experience continued practice of a task in order to improve their performance. Mental practice, however, can positively effect execution of some skills: Twining, 1949; Jones, 1963; Stebbins, 1968; Rawling Chen and Yilk, 1972, relative to a no-practice control group. Other studies have demonstrated that prior experience of the task is not essential for subjects to benefit from mental practice, (Oxendine 1969). It has been suggested that during mental practice the novice can think about possible courses of actions, and can test these out, prior to actual movement. Due to previous experience individuals can predict the possible outcomes of their actions

and disregard inappropriate responses. Such an interpretation of mental practice is closely linked to the notion of schema theory.

The study cited above represents a typical example of the type of experiments used to substantiate claims for the effectiveness of mental practice. How do we know that what the subject is doing during mental practice has the effect attributed to it? Powell (1973), tested two groups of female subjects on a dart throw skill. The first group was a positive mental practice group, who imagined hitting the bull and the second, negative mental practice group who imagined either aiming to the high righthand side, or performing an overlong throw. Those subjects who positively practiced showed a significant (28%) gain over initial performance, whereas the group who negatively practiced showed a deterioration of 3%. Powell suggests that negative rehearsal disrupts the plan necessary to throw accurately by providing false feedback to the subject. These results suggest that whatever the subject is doing during mental practice can affect execution. Furthermore, performance can improve or worsen as a result of the type of mental practice engaged in. I shall now consider some of the theoretical interpretations that have been proposed, over the last decade, to explain the mental practice effect. Examination of these will hopefully lead to the formulation of more concrete proposals, and the formulation of a testable hypothesis.

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EXPLANATIONS OF MENTAL PRACTICE

The Neuromuscular Hypothesis of Mental Practice

The electrophysiology of mental practice was pioneered by Jacobson in 1932. He attempted to find a quantitative relationship between muscular activity and mental events. Jacobson claimed he was able to measure action potentials in the muscles of small amplitudes. Sensitivity, however, was a problem using these early recording methods, so Jacobson's subjects were trained in a relaxation technique prior to participation in his experiments to keep baseline levels of muscular activity low. Any changes in activity therefore could be more readily detected.

Jacobson instructed his subjects to imagine various everyday activities, such as, putting a cigarette to one's mouth, or throwing a ball. He controlled for activity in those muscles not engaged in the task by recording from an inactive limb. Jacobson studied both imagined movement, and remembered movement. His results showed that levels of muscular activity were greater, and of longer duration, during imagined movement than for recollected movement. Recordings were also taken from the eye muscles during imagined movement, and these data revealed that activity of the ocular muscles accompanied imagined movement. Jacobson suggested this was due to the visualisation of the activity. He further proposed a distinction between imagined movement and remembered movement; in the first case the subject feels the sensations associated with the action, whereas in the second case the subject apparently views the activity as a spectator. Jacobson compared these two types of activity and found that when asked

to imagine forearm flexion, this was accompanied by an increase of activity in the eye muscles, but not in the performing limb, whereas others showed activity in the limb but not in the eyes. He concluded that this was due to the fact that some subjects made a greater use of imagery than others.

Eight years later, using more sophisticated equipment, Shaw (1940) studied imagined weight lifting. The weights lifted ranged from 100 gm to 500 gm, in increments of 100 gm, with a control weight of 200 gm. The subject was first instructed to actually lift the weight and then relax for five minutes; following this he imagined lifting the weight. This procedure was repeated for all weights in a random order. At the end of testing the subject was asked to rate imagery during mental practice on a four point scale; vague, fair, clear or vivid. The data revealed that imagery was most vivid when concurrent muscular activity increased, that is with the heaviest weights. Shaw's result must be viewed with caution as his data is based on one subject only, and furthermore the imagery ratings were purely subjective, however, they do follow¹ closely the comments made by Jacobson. These two investigators are agreed that the more vivid the imagery, the greater the activity of the muscles involved in the task being imagined. Other studies have also attempted to record muscular activity during mental practice; (Ulich, 1967; Schick, 1970). There are problems with studies such as these in that it is not clear whether vividness of imagery is a result of the activity imagined, or imagery is the precursor to that activity. Therefore, realistic interpretation of this data is difficult. ²

To summarise this section on the physiology of mental practice some tentative conclusions may be drawn. When surface electrodes are placed on large muscle groups of subjects engaged in mental practice, they detect muscular activity above normal baseline levels. There is evidence to suggest that such activity is restricted to those muscles which are involved in the task. Furthermore, it appears that any increase in muscle action potential is usually associated with imagining self-participation, rather than merely recollecting the task. Studies of implicit speech do provide some support for the neuromuscular explanation of mental practice. When subjects engage in implicit speech EMG activity reveals patterns, from the vocal musculature, that are similar to those produced when actually speaking, Schmidt (1982). If this is so then the mental performance of movement could also involve these same low level muscular forces.

Motor Programs And Mental Practice

A more recent explanation of mental practice proposes that such practice involves the initiation of the motor programs associated with the task to be executed. The idea is that the performer can run off the appropriate programs prior to execution. Two possible explanations can be put forward as to why such activity may benefit future performance. The first is that by running off the sub-programs involved in a movement sequence prior to action, the individual can begin to combine these units into a higher-order program. According to the Gearshift Theory discussed earlier, this is thought to be one method by which overt practice operates in order to refine the

task to be learned. Moreover, there is no reason to suppose that such processes, which accompany physical practice, should not be involved in mental practice, and thus achieve the same result.

The second proposal involves the neuromuscular aspects of mental practice. The suggestion is that the running of the programs associated with the skill produces low level innervation in the muscles involved in that action. As a result of this activity, the performer is able to evaluate the feedback produced which is a consequence of this low level muscular activity. Within the context of mental practice, such feedback could serve as a means by which the parameters of a generalised program can be defined. Parameters define the operating characteristics of the program which specify the particular expression of that movement sequence. For example, if the performer is required to speed up a movement sequence, he may during mental practice select various parameters so as to assess their possible success or failure in completing the sequence within a given time limit. Thus the performer may well be able to choose the most appropriate speed parameter prior to the execution of the sequence. Such a process could also apply to other parameters, such as muscle selection and force.

There is one difficulty with this particular idea; as no movement actually occurs, the feedback produced as a result of this low level innervation of the muscles may not be in terms of classic proprioceptive information. There are, however, other forms of internal feedback which can be relayed to the highest centres within the CNS (Schmidt 1982). Nevertheless,

the feedback which is the result of mental practice could operate as a means by which the parameters associated with a program for future action can be defined.

The Symbolic Learning Hypothesis

The symbolic learning hypothesis states that mental practice allows the subject to organise and learn the structure, or organisation of the constituent movements of the task. Morrisett (1967) argued that mental rehearsal will facilitate learning, only to the extent that symbolic factors are involved in the task. He further suggests that tasks that are purely motor in nature would benefit little from mental practice. As we have already said Morrisett attempted to resolve the question of which tasks will benefit by analysing the types of skills under test. Furthermore, Morrisett examined the manipulation of this symbolic component, within the same task. The task was card sorting and the symbolic component was varied by changing the rule associated with particular types of cards, and the slot into which they had to be placed. Subjects were assigned to either a mental practice or no-practice group in a high or low symbolic condition. The results revealed that in the low symbolic condition there was no difference between the groups, whereas in the high symbolic condition the mental practice group was superior to the no-practice group.

Smyth (1975) also examined skill difference, using two tasks which reflected emphasis on either the symbolic or motor component of the skill; mirror drawing (symbolic) and pursuit rotor (motor). Using a mental practice group, a

physical practice group, a control and various yoked controls, she demonstrated that during the mirror drawing task there was some improvement in the mental practice group during initial learning. On the pursuit rotor task however, the physical practice group showed consistent superiority. The subjects in the mental practice group reported great difficulty in imagining the pursuit rotor during mental practice. Smyth suggested that because the pursuit rotor is externally paced this places constraints on the subject whilst trying to imagine the task. This may be one of the reasons for the failure of mental practice to influence performance on some tasks. Furthermore, as mental rehearsal is an unfamiliar type of practice, for the majority of individuals it may be difficult for them to engage in such practice (Ergstrom, 1964)

Fitts and Posner (1967) proposed that the early stages of learning were more cognitive than the later ones, therefore we may expect mental practice to be more influential during initial learning, when the individual is attempting to form a 'gross framework' of the skill. Jones study of the hock swing upstart demonstrated that learning of a novel task can occur without demonstration or physical practice of the task. This may be because subjects, as Jones says, form a powerful kinesthetic image of the task which enables them to form their own strategies to execute the task. Jones (1963) and Summers (1977) have suggested that this symbolic component, or kinesthetic image of the task, is sequential in nature. L

It has been suggested that mental practice may only be effective in that it enhances learning about the cognitive aspects of the task, such as the sequence in which the

FIGURE 2. Mental practice situation in the ball throwing experiment.

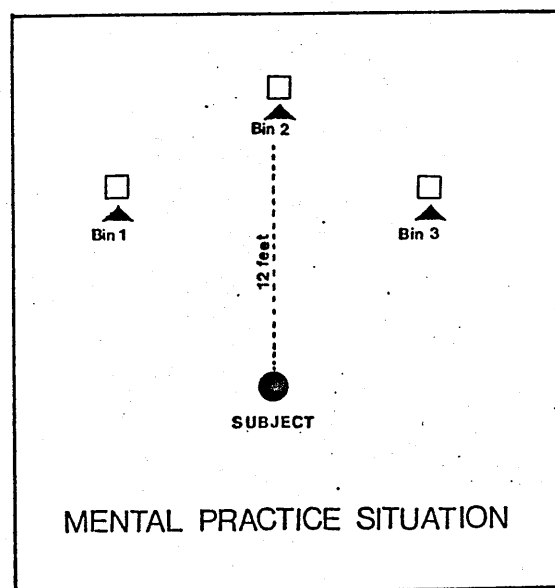


FIGURE 2

movements must be performed, and that little effect would be seen on the motor elements of the task. The studies considered so far, however, allow for no direct test of this idea as they do not differentiate, or provide independent measures of the sequential component, and of the motor acts themselves.

Dickinson (1978) attempted to provide such independent measures by employing a ball throwing task where subjects were required to throw balls into a correct bin. In order to do this subjects had to learn the sequence of correct bins. On each 10 second period within a trial only one of the bins was designated as correct, the sequence of correct bins within a trial was fixed from trial to trial. The termination of each 10 second period was marked by an auditory stimulus and a brief flash of light mounted on the bin which was correct during the prior 10 second period. Thus the subject had to learn both the correct sequence of bins, and to throw the balls accurately into the bins. Furthermore, these two aspects of the task could be measured independently. (See Figure Two)

All subjects received two pre-treatment trials before being assigned to one of four groups; physical practice (P) where subjects experienced the same procedure as in the pre-treatment phase, no-practice (NP), or no exposure to the task, mental practice (MP) and mental practice with feedback (MPF). During treatment the mental practice groups stood at the throwing position and imagined performing the task. The first mental practice group (MP) received no feedback information about the correct sequence, whereas the second group (MPF) received the light flash on the correct bins. Following

FIGURE 3. Balls in the correct bin as a percentage of total balls thrown. MPF, mental practice with feedback; MP, mental practice; NP, no-practice and PP, physical practice.

FIGURE 4. Number of bins correct. MPF, mental practice with feedback; MP, mental practice; NP, no-practice and PP physical practice.

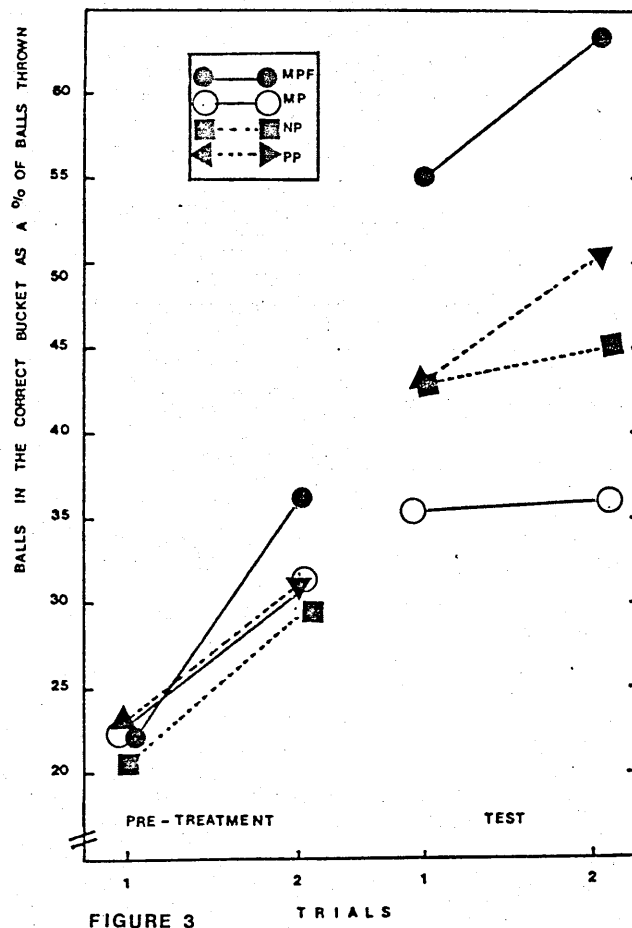


FIGURE 3

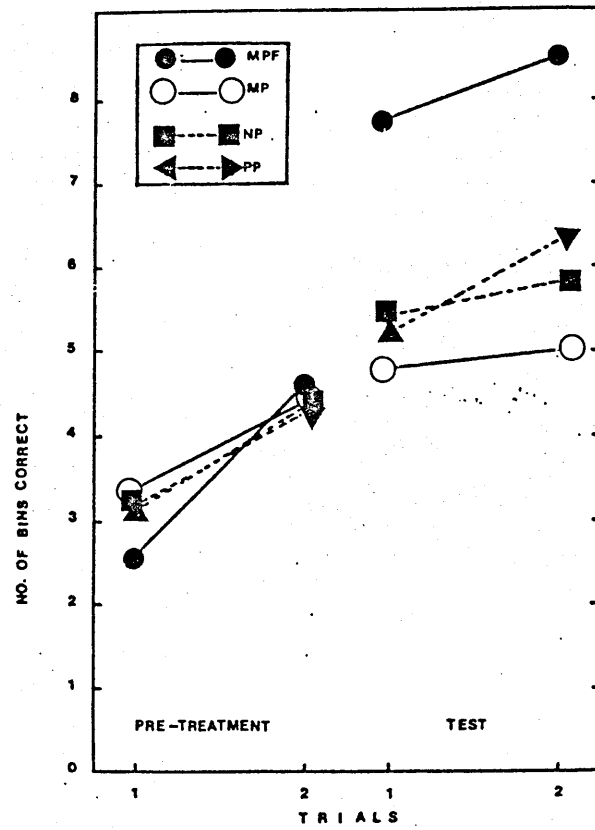


FIGURE 4

treatment stage all groups received two test trials using the pre-treatment procedure.

If mental practice is effective then Groups MPF and MP should show superior performance relative to Group NP. Furthermore, if mental practice only affects learning about the sequence aspect of the task any enhancement in performance should arise from an increase in the number of correct bins aimed at, rather than greater accuracy and speed of ball throwing per se. In addition we might expect to observe a greater improvement in performance by Group MPF which received feedback information about the sequence. These predictions were borne out by the data. Figure Three shows the performance of the groups in terms of the number of balls in the correct bins, relative to the total number of balls thrown. The performance of Group MPF was superior to all other groups. A further analysis revealed that none of the groups differed in terms of the accuracy, or speed of ball throwing. Rather the superiority of Group MPF seems to have arisen from the fact that during test they threw at fewer incorrect bins. (See Figure Four)

Dickinson's results also showed that Group MPF was superior to Group PP although this group received as much information about the task during the treatment trials. Overall the MPF Group were superior to the NP and PP Groups, and the results showed that feedback about the sequence is essential to their improvement (Group MP alone were worse than Group NP). It must be pointed out that Group MPF did receive a greater number of informative trials than Groups NP and MP. The overall significance of this finding indicates that mental

practice allows the subject time to plan his strategy, learn the sequence and rule out incorrect responses.

Subjects in Group MPF had the opportunity to rehearse the sequence component without monitoring their motor responses which gave them some advantage over the physical practice group. This raises the question of the nature of this advantage. Two possible interpretations to this problem are apparent. First, subjects engaged in physical practice are required to divide their attention between learning the sequence and performing the motor acts themselves. This results in a disruption of both sequence learning and execution of the movements. By contrast, subjects engaged in mental practice learn the sequence prior to attempting the task. With this accomplished they were in a position to execute the task with accuracy.

The second possible interpretation is that the underlying motor control systems operate differently in the two groups. Initially, physical practice demands that subjects switch between different states of control, to both learn the sequence and execute the movements. By contrast, mental practice subjects would not be required to switch between these different states, and would be ready for action on the first trial of acquisition. Both these interpretations are speculative, but begin to provide pointers as to why mental practice facilitates performance on this task.

VARIABLES MANIPULATED IN MENTAL PRACTICE STUDIES

Time Of Mental Practice

One of the variables manipulated in the mental practice situation is the time allowed for such practice. The data

reveals a diversity of results on this dimension. The range of times employed vary from one minute, (Schick,1970) to 50 minutes (Vandell, Clugston and Davis, 1945). Twining (1949) considered this variable in some detail. He examined a ring toss task using 36 male subjects, assigned to one of three groups. Subjects in a control group, threw 210 rings on the first and twenty-second days of the experiment. The second group, the physical practice group, threw 210 rings on the first day, and from then on, to the twenty-first day threw 70 rings each day. The final group, the mental practice group also threw 210 rings on the first day, but from then to the twenty-first day rehearsed mentally for fifteen minutes daily from the second to the twenty-first day. Twining attempted to keep motivation high by making the subjects note their own scores. The instructions given to the mental practice group was to visualise all the 'sensations' associated with the task.

Analysis was in terms of difference scores of performance on the first and twenty-second days of the experiment. Results showed that both physical practice and mental practice groups were significantly better than the no-practice control group. In the mental practice group, rehearsal lasted for fifteen minutes, whilst in the physical practice group the time taken to toss 70 rings averaged 7½ minutes, which is half the time devoted to mental practice. Furthermore, subjects in the mental practice group found it difficult to carry out such practice for fifteen minutes, and from subjective data collected it appeared that the optimal period for mental practice was five minutes only. Despite these difficulties, the experiment demonstrated that mental practice

can be as effective as physical practice. As a result of these data most studies use no more than five minutes mental practice, and when a greater length of time is desired then rest periods are inserted between mental practice periods. The fact that distributed mental practice appears to be more effective than unspaced practice is supported by Corbin (1972).

Mental Practice And Type Of Skill

Some investigators have indicated that mental practice may only benefit the acquisition of certain types of skills. As we have seen perceptual-motor skills can be analysed into two components, (Dickinson 1978). The first, a cognitive, or sequential element, and the second, the motor acts themselves. Morrisett (described by Richardson 1967) rated various skills in terms of whether they were high or low in symbolic content and motor element. If, as suggested by Morrisett, it is the symbolic component of the skill, rather than its motor components that determine whether mental practice will benefit subsequent performance, then an analysis of the skill itself will be essential to any study of mental practice.

Morrisett had judges independently rate two tasks, the finger dexterity task, which was considered to be high on the motor element and low on the symbolic component, and by contrast a two handed coordination task which was rated as the reverse. Mental practice studies were conducted using both these tasks and revealed that its effects were greater on the task with the high symbolic component. This evidence supports Morrisett's hypothesis that mental practice generally improves performance where the symbolic content of the skill to be

acquired is high. The question is what does Morrisett mean by 'symbolic' component? Furthermore, how is he defining 'high', is he referring to the amount of central processing that might be involved in the task? I assume that Morrisett and I are in agreement on this point, in that the symbolic aspects of a motor skill refer to the organisation and structuring of the movements, rather than execution of the motor acts.

Mental Practice And Task Difficulty

Task difficulty is another variable which has captured the attention of researchers in this area. If Morrisett is to be believed however, then difficulty would make little difference to the overall benefits of mental rehearsal as it is the nature of the task itself which determines any improvement in performance. Phipps and Morehouse (1969), on the other hand, have argued that the difficulty of the task may indeed determine the relative effect of mental practice. They studied three tasks, the hock swing upstart, the jump foot and the soccer hitch kick. From a previous pilot study of a random population of male university students, it was shown that the three tasks differed systematically in difficulty, in terms of the percentage of subjects who could successfully perform them. Each performance of the task was assessed on a pass or fail criterion over ten attempts. The subjects, seventy-two males were assigned to either a control, or mental practice group. The tasks were novel to all participants. The control group was given demonstrations of the task and the criterion for a successful attempt was described. The same procedure was used for all three tasks. The experimental group met and engaged

in mental practice. The mental practice group were shown a demonstration of the task during this practice period. The subjects were then instructed to close their eyes and imagine themselves performing the skill as a description of it was read to them.

Following three days treatment all subjects were tested. Phipps and Morehouse found that the only significant difference between the mental practice and the controls was on the hock swing upstart, the easiest task. No different was found between the groups on the other two skills. These data support Jones (1963) findings who also used the hock swing upstart, but did not include a no-practice control group.

The data from Phipps and Morehouse's experiment is difficult to interpret as they have ignored the possible effect of directive mental practice which would limit the subject's ability to develop his own strategies that might accomplish the task. Furthermore, whilst demonstration avoids confusing mental practice with physical practice it is thought to significantly alter levels of motivation, particularly in the case of male subjects. Both these factors may have played a part in biasing the subjects in favour of the simpler skill.

Schedules of Mental And Physical Practice

One of the problems in considering the type of skill as a variable is the possibility that subjects have had some prior experience of the task (Steel, 1952; Shick, 1970; Whitley, 1962; Ammons, 1951). As a consequence, many experiments have used various schedules of mental practice, preceded by different amounts of physical practice, in order to determine

whether the physical practice accelerates acquisition to a greater extent than mental practice alone. Oxendine (1969) examined three tasks, the basket ball jump shot, the soccer kick and the pursuit rotor. These tasks were tested under different schedules of mental and physical practice. Subjects were assigned to one of four groups, a physical practice group, or one of three other groups in which the amount of physical practice was systematically reduced from 8 to 2 trials with the remaining trials administered under the mental practice condition. The treatment lasted for a total of seven days.

On the pursuit rotor task, analysis of the first day scores revealed no significant difference between those subjects who had received 8 physical practice trials and those who received 6 physical practice trials together with 2 mental practice trials. The performance of these two groups, however, was superior to all other groups. For the soccer kick task no significant difference was found on the pre-test scores or on the test which occurred on day 8, although all groups showed improved performance. The final task, the basketball jump shot, again showed no significant difference on test, with all groups showing little improvement.

Oxendine concluded from these results that, if the skill is within the capacity of the learner, up to half of the trials given can be mental practice trials, rather than physical practice. This statement, however, is based on mean values in the data tables, and not on differences supported by statistical analysis.

Many researchers feel that some physical experience of the task is essential if any benefits are to be felt following

mental practice, although there are exceptions to this view. Jones (1963) tested 71 subjects on a simple gymnastic skill (hock swing upstart). Two groups were used, one a directed mental practice group, the other a non-directed mental practice group. The information given was a mechanical description of the task. On a pass or fail criterion 56% of subjects passed the test at their first attempt, demonstrating that learning can occur without physical practice. Jones went on to assess whether the directed or non-directed variable had any influence on the learning of the task. He found that the non-directed mental practice group were superior to the directed group. Jones argued that undirected practice leads to the formation of a better 'kinesthetic image', and that the individual is able to generate a response with an integrated action plan already at his disposal.

Subjective Organisation And Mental Practice

From Jones' study it would appear that non-directed mental practice is most beneficial, it might be argued that such practice allows the individual to test out his own strategies which will enable him to perform the task. This idea is similar to that proposed by Tulving (1962), who suggested that during verbal learning, if subjects are allowed to structure and organise incoming information idiosyncratically, they show improved recall and performance on test, relative to a condition in which organisation is imposed on the information prior to processing by the subject. This notion is supported in the mental practice literature by Bole (1976).

Mental Practice And Knowledge Of Results

It is generally assumed that the learning of a task, or skill, only occurs when knowledge of results, or knowledge of performance is available (Bilodeau, 1969; Adams 1971). These types of feedback provide different types of information. Knowledge of results provides information about goals or outcomes, whereas knowledge of performance provides data about the movements themselves. The difficulty for mental rehearsal is that if no actual movement is made then how can KR and KP occur, and if they do not, how can the subject learn from mental practice?

Newell (1974) demonstrated that learning without knowledge of results is possible and error reduction can occur in a rapid linear timing task, but that it is dependent upon a recognition mechanism and the possible use of feedback during response production. Williams and Rodney (1978) provided support for learning without KR, they call upon the notion of a recognition schema in order to interpret their results. Using a linear position task, subjects were divided into two groups, the first group moved to a target position on the slide bar, whereas the second group moved to a series of randomly ordered stops around the target. These subjects were informed that the location of the target was in the centre of this random series. Further trials followed with the subject attempting to move to the target. Both groups did equally well on the first no-KR trial but as trials progressed, subjects who had experienced the random sequence maintained their level of performance, whereas the others did not. These results can be explained if we call upon schema theory, in that by using a

recognition schema subjects can generate the expected sensory consequence of being at the correct location without prior experience of it. The subject is therefore able to match actual and expected sensory feedback to position the lever correctly.

According to schema theory (Schmidt 1975) novel movements can be generated given that the subjects possess two types of information, first the initial conditions, and second the desired outcome of the movement. Once the subject has this information they can determine the response specifications necessary to achieve the goal (Recall). The second part of this mechanism is the relationship between sensory consequences and actual outcomes as modified by initial conditions (Recognition). Given these two relationships there is no reason to suppose that subjects cannot perform movements they have never experienced. The idea of a motor schema provides a theoretical basis for the production of novel movements in the absence of knowledge of results.

In this context mental practice could operate either within the recall or recognition schema, that is it could serve to facilitate relationships between initial conditions and outcomes which would allow the individual to generate the response specifications in order to achieve the goal. During mental practice the individual has the opportunity to try out possible strategies, the consequences of which could be predicted on the basis of past movement experience. Such activity would allow the subject to rule out many possible responses and limit his movements to those that are most appropriate.

SUMMARY

In this section I have reviewed three theories of how mental practice might work; the neuromuscular hypothesis, the motor program theory and the symbolic learning supposition. Although there is little doubt that covert motor activity can occur during mental practice, there is little evidence that such activity is causally related to subsequent performance. The motor program theory put forward the notion that mental practice consists of 'running off' a program in an attenuated form. This may indeed facilitate learning of the sequential component of the task. Another possibility is that by running the program prior to performance it in some way prepares the participant for execution of the movements, for example it may pre-set levels of arousal. The symbolic learning hypothesis does receive support from a variety of sources. Dickinson demonstrated that the main effect of mental practice was on the sequential component of a complex skill. It might be argued that this result is constrained by the artificial structure of the task employed, in order to allow for separate measures of the sequential and motor aspects of the task.

This introductory overview of mental practice has also introduced the reader to some of the methodological and theoretical issues involved in such practice. The discussion so far has revealed that, for some skills, mental practice does produce changes in performance which can either be positive or negative depending on what the subject rehearses. The question of whether mental practice improves performance without access to knowledge of results is still controversial.

Theoretically, at least, it is possible that certain skills can be learned without physical practice.

Dickinson (1978) has provided support for the idea that mental practice does affect the learning of the sequential component of a gross motor skill. The experiments reported in this thesis expand on this proposal and the purpose of the investigations will be to study the effect of mental practice on a complex skill. This task will allow for separate measures of the sequential and motor components of the task to be assessed and furthermore, may give us some pointers as to how they interact to determine overall performance.

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CHAPTER THREE

MENTAL PRACTICE
AND INTERACTIVE SKILLS

	PAGE NUMBER
EXPERIMENT ONE	44 - 51
Method	47 - 48
Results	48 - 50
Discussion	51 - 51
The Runway	51 - 52
EXPERIMENT TWO	52 - 62
Introduction	52 - 54
Method	54 - 56
Results	56 - 58
Discussion	58 - 62
EXPERIMENT THREE	62 - 67
Introduction	62 - 62
Method	63 - 64
Results	64 - 65
Discussion	65 - 67

MENTAL PRACTICE AND INTERACTIVE SKILLS

My previous study (Dickinson, 1978) showed that mental practice could facilitate learning about the sequential component of a gross motor skill; the significance of this finding was limited, however, by the fact that the task was not of an interactive nature. The definition of such a task is that performance of each movement must take into account the preceding, and following movements; for example, walking. In order to extend the analysis of mental practice, a task was needed which reflected the interactive nature of gross motor skills and so the aim of the first experiment was to develop a task which was interactive in character, whilst retaining the ability to measure the extent to which the subject learned about the sequential component of the task.

EXPERIMENT ONE

In 1932, G.B. Johnson designed a test to determine native differences in physical skills. The test was intended to overcome the specificity of existing tests, which Johnson considered dealt only with particular skills, and not general motor ability. The task was unusual enough to avoid the possibility that subjects may have had experience of it, and furthermore, it required no special speed or endurance abilities but only those that might be required in normal locomotion. The test consisted of various movements made

FIGURE 5. Two examples of Johnson's task.

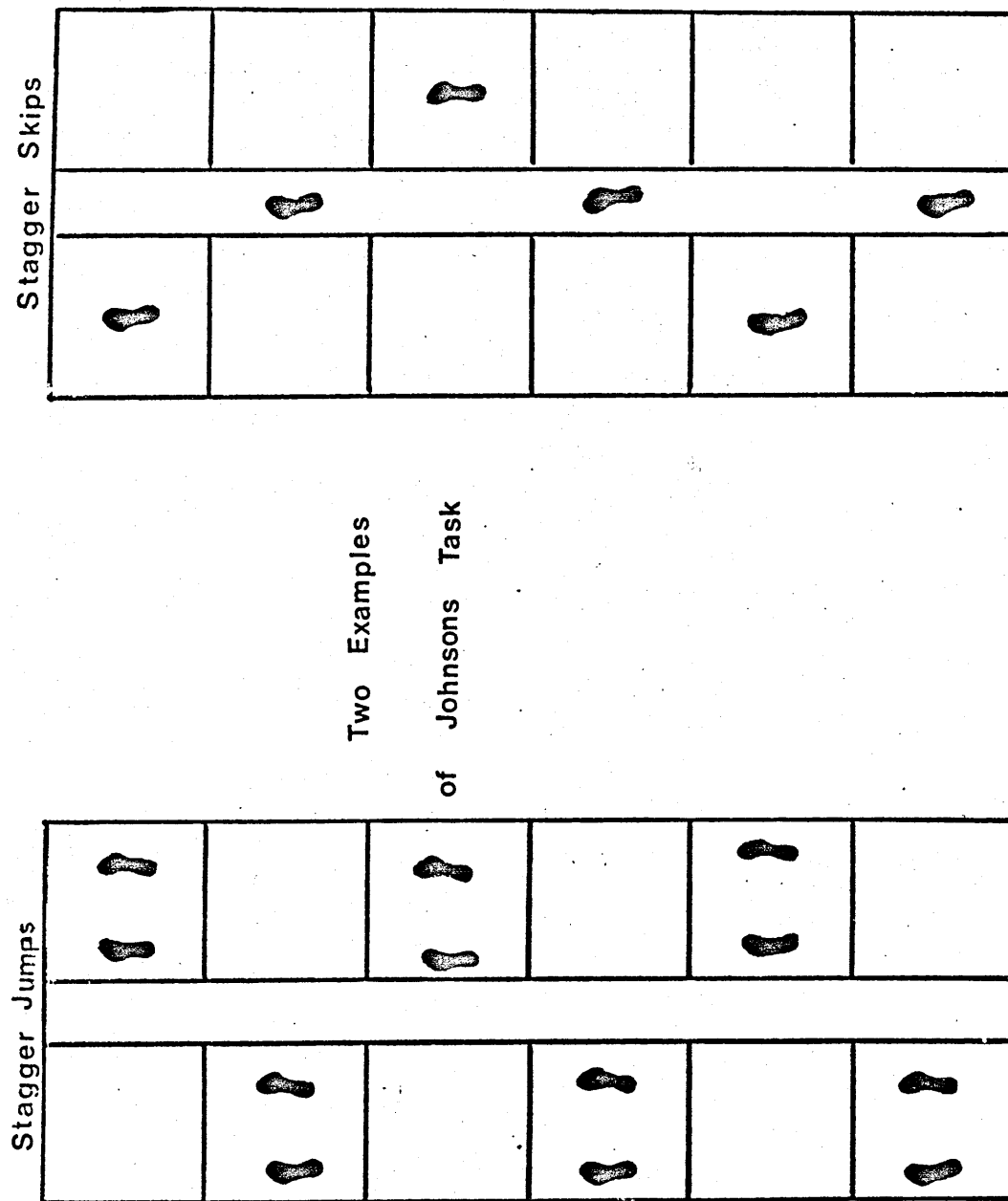


FIGURE 5

along a matrix of squares. These movements included straddle jumps and jumps with turn. (See Figure Five)

It was decided to adopt Johnson's task to study the effects of mental practice on learning. The task consisted of learning to perform a pre-determined sequence of hop-scotch like steps along a matrix of squares, as fluently and rapidly as possible. Before embarking on a major study of mental practice with this task however, it was necessary to show that it produced acquisition functions, characteristic of learning a gross motor skill.

At the start of the experiment subjects were shown a diagram illustrating the squares on which they should step, and those they should avoid. They were then allowed to perform one trial; if they made an error, either of commission by stepping on an incorrect square or of omission by failing to step on a correct square, they were allowed to inspect the diagram again. The subjects performance on each trial was measured in terms of the number of errors made on that trial, and the speed and fluency of each traverse of the runway. The number of errors would indicate the rate of sequence learning, and I expected to observe a progressive decrease in errors across trials. Furthermore, the error pattern was also subjected to a serial position analysis, so that if acquisition of the sequence information followed the conventional pattern, we should expect to observe an inverted U-shaped serial position curve. The performance of all subjects was recorded on a video to allow for analysis of the fluency of execution. As I had no prior indication of the rate of learning for this task, two levels of difficulty were used, task

easy (TE) and task difficult (TD). In the TE condition subjects had to learn to perform a regular pattern of foot movements, whereas in the TD condition an irregular pattern was employed.

In the introduction to this thesis it was proposed that mental practice will facilitate learning to the extent that it operates on the organisation and structuring of the symbolic elements of a task. Such processes are thought to function at a high level within the motor system where the sequence component is represented, and is not thought to be directly involved with the motor acts themselves. Evidence from Summers (1977) suggests that learning through mental practice will only occur to the extent that sequential factors are involved in the task. He cites the Suzuki violin method as an example of the establishment of sequences in memory prior to performance. The idea is that children taught by this method can store a 'musical template' of the sequences of movements which will enhance later performance. This allows them to recognise errors in sound production and the sequence of movements that lead to that sound.

If mental practice works by structuring the sequence component and facilitates its storage, rather than directly influencing the motor acts themselves, then such practice should only be effective if performance is sensitive to factors relating to the access and processing of this type of symbolic information.

In order to decide whether learning could be modulated by access to symbolic information, in the form of knowledge about sequence the subjects in the easy and difficult conditions

FIGURE 6. Sequence for Task Easy and Task Difficult.

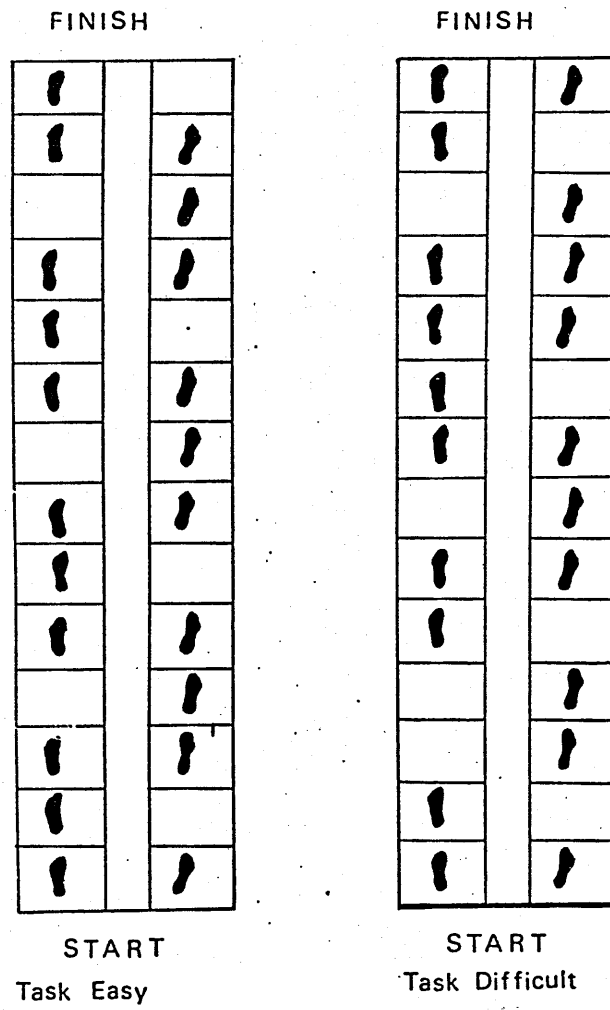


FIGURE 6

were allowed either a short or long period to inspect the diagram which specified the correct sequence. Thus the experiment had a 2 x 2 factorial design with the difficulty of the sequence as one factor and inspection time as the other.

METHOD

Subjects

Twenty subjects, all female aged between 19 and 21 years, were assigned to one of four groups: TE/30, TE/120, TD/30, TD/120.

Apparatus

The runway used in this study was a matrix of squares 15 x 2 made up of standard commercial floor tiles (23cm x 23 cm) glued to a large plastic sheet. The sequence consisted of one foot to one foot movements, one foot to two feet, and two feet to one foot movements. The sequences for this task are illustrated in Figure Six.

Procedure

The first variable was the two levels of difficulty with the second being the time the subject had to inspect the instruction sheet, either 30 seconds or 120 seconds. The subject first inspected the sequence instructions for the appropriate time depending upon the group to which they had been assigned. The subject then attempted to reproduce the foot pattern on the runway. If they made one or more errors, they received a further inspection period for the appropriate time before the next trial. This procedure was continued for

six trials, and every trial was recorded on a Sony Videocorder for later analysis.

Measures Of Performance

Sequence learning was indexed by the number of errors made on each trial, and speed was measured as the time taken to complete one traverse of the runway. The final measure was a qualitative evaluation of performance and two factors were used to rate the subjects' performance, these were balance and rhythm. Balance was defined as the ability to make postural adjustments with respect to the pull of gravity. Judges who rated the task found they could more easily decide whether a subject was off balance, rather than assess how well the movements were executed per se. Similarly, in the case of rhythm the judges were instructed to look for a regular pattern which emerged over trials for any one subject. Each of these factors was rated on a five-point scale and the fluency of performance was the sum of both scores. In order to test the reliability of this measure the video tapes were rated by two judges. The Spearman Rank correlation coefficient between these judges was 0.87. It should be noted that no a priori claims are being made about the independence of these various measures of performance.

RESULTS

Each performance measure was analysed by a three-way mixed ANOVA with Inspection Time and Task Difficulty as between subjects factor and Trials as a within subjects factor. (See

Tables A - C in Appendix.)

FIGURE 7. Mean number of errors for all the various groups, TE-30 task easy, 30 seconds, TE-120 task easy 120 seconds, TD-30 task difficult 30 seconds, TD-120 task difficult 120 seconds.

FIGURE 8. The mean number of errors for all groups as a function of the serial position of the error. TE-30 task easy 30 seconds, TE-120 task easy 120 seconds, TD-30 task difficult 30 seconds, TD-120 task difficult 120 seconds.

FIGURE 7. Mean number of errors for all the various groups. TE-30 task easy, 30 seconds, TE-120 task easy 120 seconds, TD-30 task difficult 30 seconds, TD-120 task difficult 120 seconds.

FIGURE 8. The mean number of errors for all groups as a function of the serial position of the error. TE-30 task easy 30 seconds, TE-120 task easy 120 seconds, TD-30 task difficult 30 seconds, TD-120 task difficult 120 seconds.

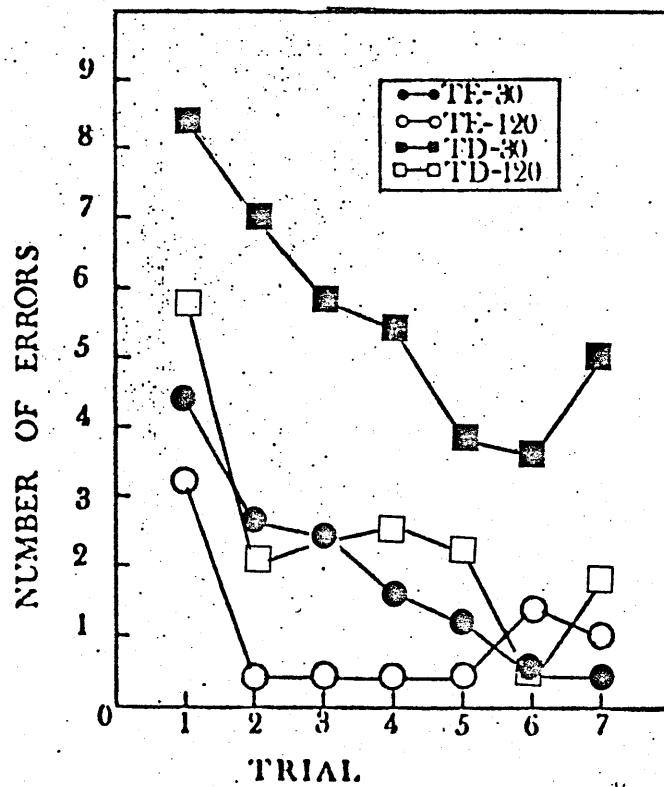


FIGURE 7

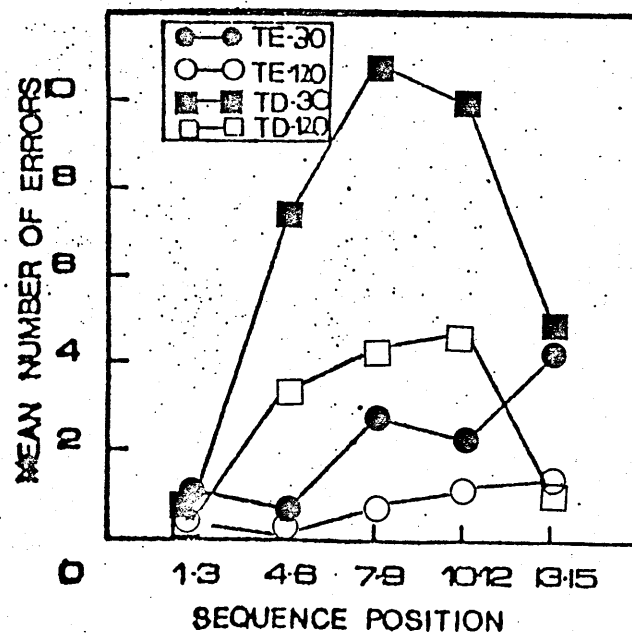


FIGURE 8

Sequence Learning

Sequence learning was measured by the number of errors made on each trial. Figure Seven illustrates the mean number of errors on each trial. All groups showed a progressive decrease in the number of errors per trial, $F(6,96) = 6.87$, $P < 0.01$. Irrespective of the length of instruction time, however, subjects performing the easy task made fewer errors than those performing the difficult task, $F(1,16) = 20.8$, $p < .01$. Similarly, those subjects with the longer inspection time made fewer errors than those with the shorter inspection time, $F(1,16) = 12.2$, $p < .01$. There was no significant interaction between the effects of Task Difficulty and Inspection Time, $F(1,16) = 4.11$, n.s., and neither of these factors was involved in interactions with Trials, $F < 1$, in all cases.

Figure Eight shows the number of errors for each groups averaged over all acquisition trials as a function of the serial position of the error. Subjects performing the difficult task with an inspection time of 30 seconds showed pronounced recency and primacy effects. A similar pattern was shown by subjects performing the difficult task with 120 inspection time, although the effect was not as marked. There was no evidence for such an effect on the easy condition.

Speed

Figure Nine shows all groups performed faster with experience, $F(6,96) = 8.47$, $P < 0.01$, and that irrespective of instruction time, subjects performing the easy task were faster than those performing the difficult task, $F(1,16) = 12.1$, $p < 0.01$, although in this case there was no significant effect

FIGURE 9. Mean speed of the various groups, TE-30 task easy 30 seconds, TE-120 task easy 120 seconds, TD-30 task difficult 30 seconds, TD-120 task difficult 120 seconds.

FIGURE 10. Mean performance rating of the various groups, TE-30 task easy 30 seconds, TE-120 task easy 120 seconds, TD-30 task difficult 30 seconds, TD-120 task difficult 120 seconds.

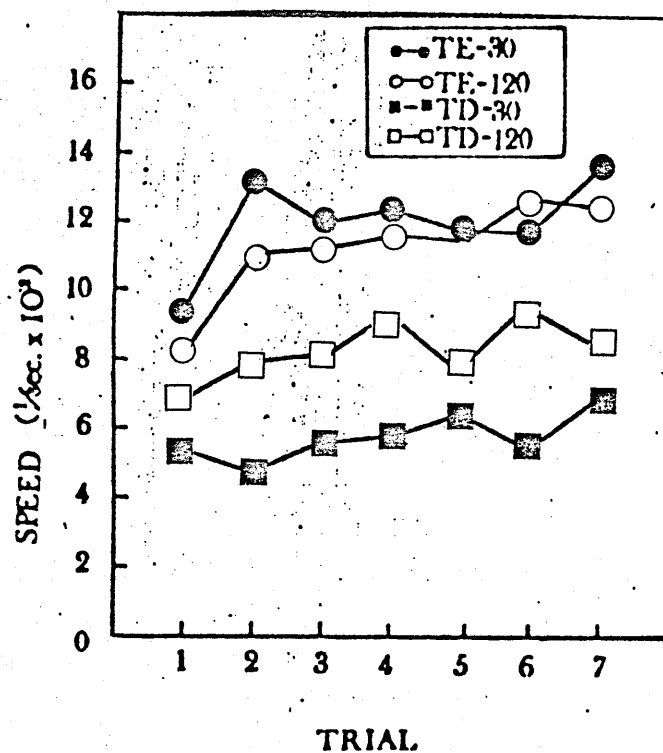


FIGURE 9

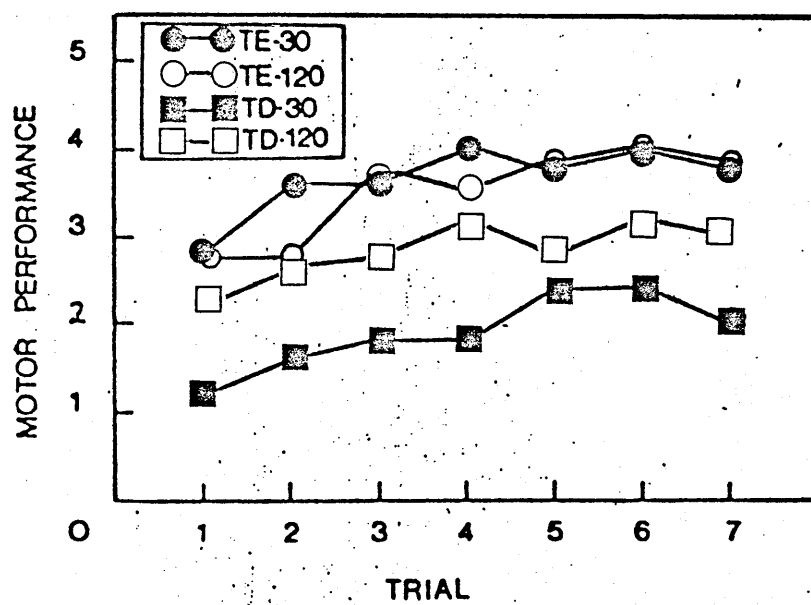


FIGURE 10

of inspection time, $F < 1$. Figure Nine does suggest however, that Inspection Time had an effect in the difficult condition but this was not supported by a significant Difficulty x Inspection Time interaction, $F(1.16) = 1.45$ $p > .10$. There was however, a significant Difficulty x Trials interaction, $F(6.96) = 2.45$, $P < .05$ which possibly reflects the greater increase in speed shown in the early condition. All other interactions involving Trials failed to reach significance (all $F(6.96)$'s < 1.70).

Fluency

The third measure of performance was a qualitative assessment of the movements which also showed a general improvement across trials, $F(6.96) = 10.33$, $P < .01$. Figure Ten displays the mean ratings of each group and reveals that irrespective of instruction time subjects performed the easy task with greater fluency than those performing the difficult task, $F(1.16) = 13.50$, $p < .01$.

The graphic data suggests that there was an interaction between task difficulty and inspection time although the presence of this interaction was not supported by statistical analysis. Neither the main effect of Instruction Time, $F(1.16) = 1.43$, $p > .10$, nor the Instruction Time x Difficulty, $F(1.16) = 2.64$ were not significant. There were no significant interactions involving Trials $F(6.96) < 1.17$ ~~ms~~ in all cases.

DISCUSSION

The runway task would seem to be an excellent paradigm for the proposed investigations, as performance at least in terms of the sequence errors is susceptible to both the difficulty of the sequence, and manipulation of inspection time. Moreover, this measure also showed a typical acquisition function and serial position error function. The other two measures did not appear to be as sensitive to the manipulation of inspection time, although they did show reasonable acquisition functions and differentiated tasks of varying difficulty. On balance this pattern of results suggests that the tests and measures are suitable for the acquisition of a complex interactive skill and consequently I decided to adopt this paradigm in future investigations of the mental practice phenomena.

The Runway

In order to overcome some of the difficulties encountered in timing, and to provide feedback correction to the subject during execution a more sophisticated runway was designed and constructed. A rubber mat 20 feet long was divided into fourteen adjacent squares (34 cm x 34 cm). Each square was covered with electrically conductive paint (Johnson Matthey Type FSP 15) and separately connected to one pole of an electronic switch. During performance the subject was connected to the other pole via an electrode attached to the skin flap between the thumb and forefinger of the left hand. As the subject performed the task barefoot, this system allowed the control and recording apparatus to detect when they were in contact with any particular square.

The first pair of squares will be referred to as the start squares, and as soon as the subject lifted either foot from these squares, a break in the electronic switch started a timer, this was stopped automatically when the subject made contact with either of the last pair of squares. The control apparatus allowed any square of the remaining 12 pairs to be wired with a specific sequence. This could include the following alternatives; the right square, the left square both squares and neither square. If the subject made contact with a 'wired' square an electronic counter was incremented and a feedback tone was generated for as long as the subject maintained contact with that square. In the experiments to be reported the subjects task was to traverse the runway stepping only on those squares designated as correct. On the runway any sequence could include the following movements; two feet to two feet, two feet to one foot or one foot to one foot. Overall, the movement sequence was similar to a complex form of hop-scotch.

EXPERIMENT TWO

Introduction

The primary aim of the next experiment was to extend Dickinson's (1978) findings on the beneficial effects of mental practice to an interactive skill. Subjects received mental practice prior to experience with the task and were then required to traverse the runway, using trial and error learning. Their performance was assessed in terms of three performance measures, sequence error, speed and fluency. A

second aim was to see whether the effect of mental practice depends upon the stage at which it is introduced. In the earlier discussion of the various explanations of mental practice it was pointed out that the stage at which such practice is introduced might be a critical factor.

The proposal is that the symbolic representation of the task is sequential in nature and that it is this aspect that must be acquired before the appropriate movements can be made. Therefore, if we present subjects with the symbolic information, in this case the step sequence, and give them the opportunity to mentally rehearse it, then such rehearsal should enhance learning when the time for action arrives.

The second aim of this study was to assess the effectiveness of mental practice with reference to the stage at which it is introduced. If mental practice functions by consolidating some form of motor 'image', then prior experience of the task would be required in order for the subject to operate on that image. By contrast, if mental practice operates on some form of symbolic representation, however, then such practice could be effective in the absence of actual performance.

In this study the subjects were required to traverse the runway as quickly and accurately as possible, stepping only on the square designated as correct. One group received mental practice prior to exposure to the task, and as they had no previous experience with it guidance cues had to be presented during mental practice. These cues were provided by overlaying the runway with cardboard foot-prints illustrating the correct sequence. The physical practice group actually performed

FIGURE 11. A schematic diagram of the runway showing the movement sequence,

traverses of the runway in the presence of these same guidance cues, whereas the no-practice group had no training prior to initial acquisition. Equivalent groups were run in which subjects had some previous knowledge of the task, in that they performed initial acquisition trials, prior to their various treatments.

METHOD

Subjects

Thirty-six female students aged between 18 and 25 years were randomly assigned to one of six groups; early guided mental practice (GMP), early guided physical practice (GPP), early no-practice (NP) and late guided mental practice (GMP/L), late guided physical practice (GPP/L) and late no-practice (NP/L)

Apparatus

The runway was the twenty foot long rubber mat as described earlier. Across the successive twelve pairs of squares the following were designated as correct; left, right, left, left and right, right, left and right, left and right, right, right, left. The sequence included the following transitions: two feet to two feet, two feet to one foot, one foot to two feet, and one foot to one foot. This sequence is illustrated in Figure Eleven.

In order for a record to be made of the subjects performance a video recording was made of all subjects on every trial using a Sony Videocorder and a Sony camera fitted

with a wide angle lens. The video recordings were used for rating the subjects fluency.

Procedure

The experiment was divided into three stages: pre-training, training and test. (See ~~Table One~~) During test the subject's task was to traverse the runway stepping on only those squares designated as correct. If the subject made contact with an error square a feedback tone sounded informing the subject that the square was not part of the correct sequence.

Where?
At
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Appendix
Refer
to this

Pre-Training

During pre-training subjects in Group GMP/L, GPP/L and NP/L performed five trial and error traverses of the runway with feedback correction.

Training

Following pre-training Group GMP/L were instructed to imagine themselves performing the task. Each subject stood on the two start squares and performed ten imaginary trials. Subjects were asked to turn their heads to the right following the completion of each imaginary trial so the experimenter could record the number of trials completed. During imaginary practice the guidance cues were used, to ensure the subject rehearsed the correct sequence. For subjects in Group GPP/L the same conditions applied except that these subjects were required to actually perform the task. While Group GMP/L and GPP/L received their different types of practice, Group NP/L completed a simple reading task.

FIGURE 12. Mean sequence error of the various groups in the early (top panel) and late conditions (bottom panel). GMP, guided mental practice; GPP, guided physical practice; NO, no-practice.

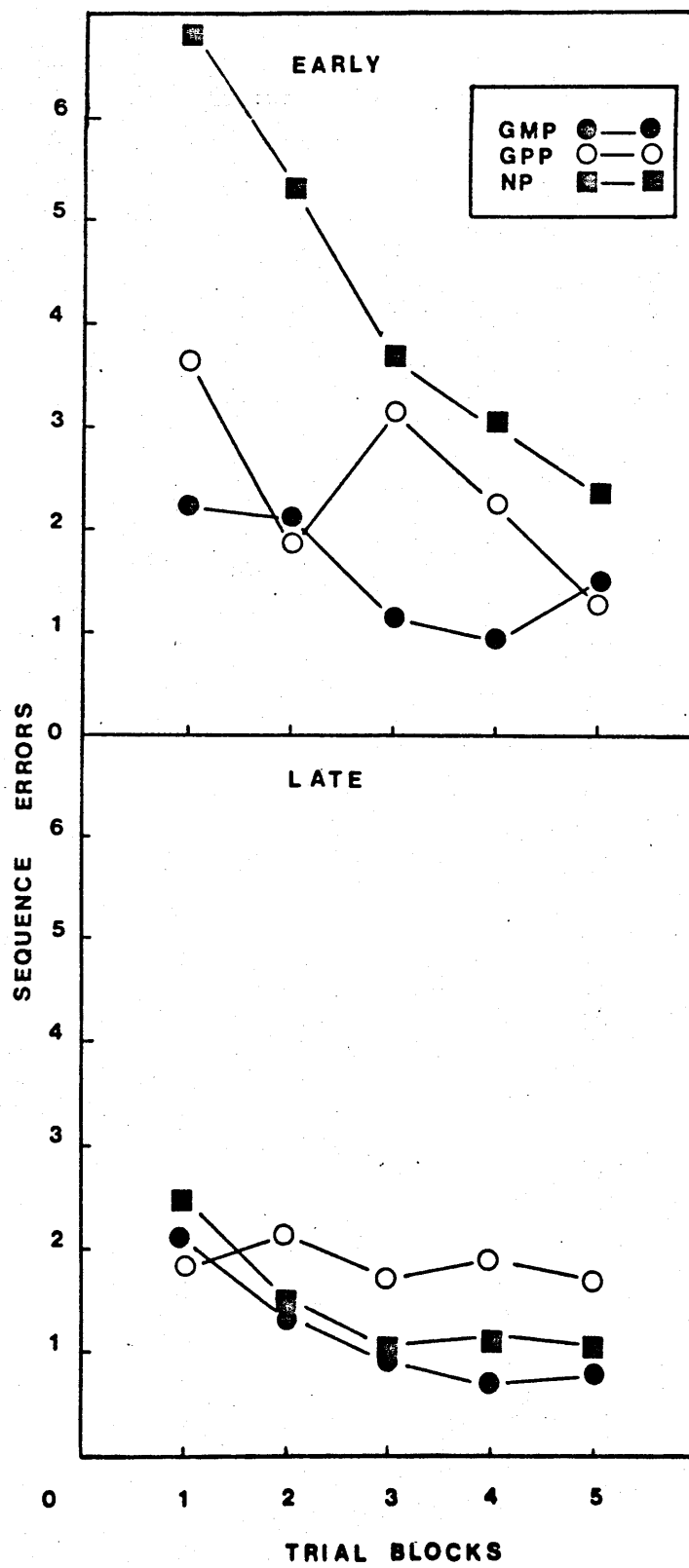


FIGURE 12

The subjects in the early condition Groups GMP and GPP had no pre-training, and did not experience the task prior to their five guided mental, or physical practice trials respectively. The no-practice group (NP) in the early condition had no training at this stage.

Test

Following training all six groups performed fifteen test trials, without guidance using trial and error learning. The only feedback they received about the correctness of their performance occurred as the movements were executed. Subjects had a three-way decision to make at each pair of squares; that is, was the right foot, the left foot, or both feet correct.

Measures Of Performance

The performance of subjects during test was assessed in terms of three measures; sequence error, speed and fluency.

RESULTS

Sequence Learning

Figure Twelve illustrates sequence learning of the different groups in the early and late conditions. The error scores were analysed by a three-way mixed analysis of variance with the training condition (Group) and the time of training, early versus late (Stage) as between subject factors and trials as a within subject factor. ~~In both the early and late conditions~~ the error rate decreased over trials, $F(4,120) = 15.96^5$, $P < .01$, Overall

*ANCOVA
Refer to Tables D & E
in Appendix*

FIGURE 13. Mean speed of the various groups in the early (top panel) and late conditions (bottom panel). GMP, guided mental practice; GPP, guided physical practice; NP, no-practice.

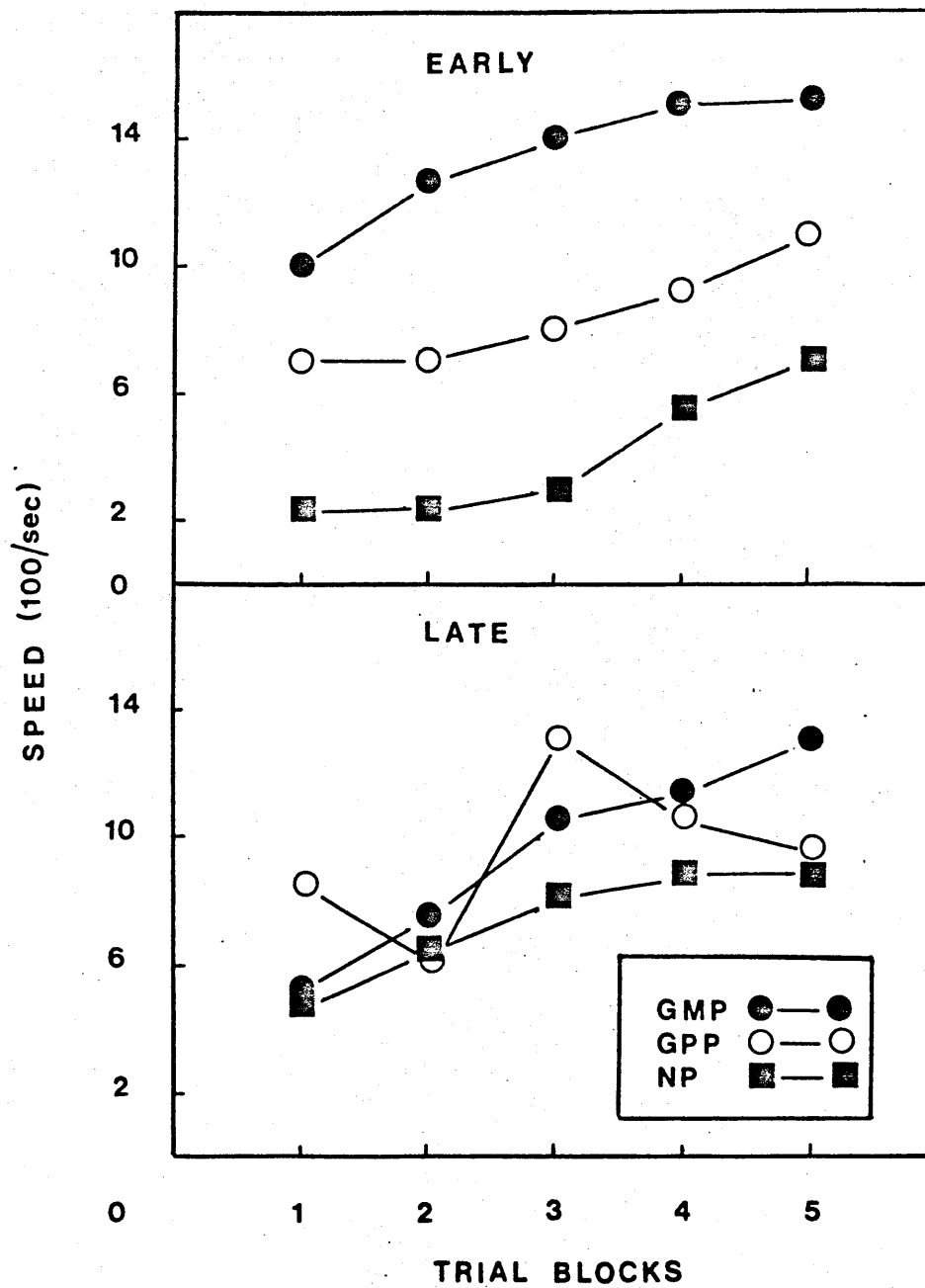


FIGURE 13

and on average fewer errors occurred in the late condition than in the early condition, $F(2,30) = 7.97, P < .01$.

Although the presence of a significant main effect of groups, $F(2,30) = 4.05, P < .05$, indicates that performance was affected by the training condition, a significant Stage x Group x Trial Interaction, $F(8,120) = 2.32, P < .05$, supports the suggestion in the graphic data (Figure Twelve) that the size of this effect depended upon the time of training and trial. In order to explore this significant interaction, the sequence errors were analysed separately for the early and late conditions using the mean square error rate from the overall analysis. These analyses revealed a significant effect of groups in the early condition, $F(2,30) = 6.74, P < .01$, but not in the late condition $F < 1$. Individual comparisons by the Neuman-Keuls procedure showed that subjects in Groups GMP and GPP committed fewer errors than subjects in Group NP in the early condition, $P < .05$ in both cases.

Speed

Figure Thirteen illustrates the speed of the various groups in the early and late conditions. In both conditions speed of performance of all groups improved over trials, $F(4,120) = 29.17, P < .01$, although there was no difference in the speed of subjects in the early and late conditions, $F < 1$. Overall however, there was a significant effect of groups, $F(2,30) = 8.11^{\circ}, P < .01$. Although the graphic data suggest the groups difference were largely confined to the early conditions, the




FIGURE 14. Mean fluency ratings of the various groups in the early (top panel) and late conditions (bottom panel). GMP, guided mental practice; GPP, guided physical practice; NP, no-practice.

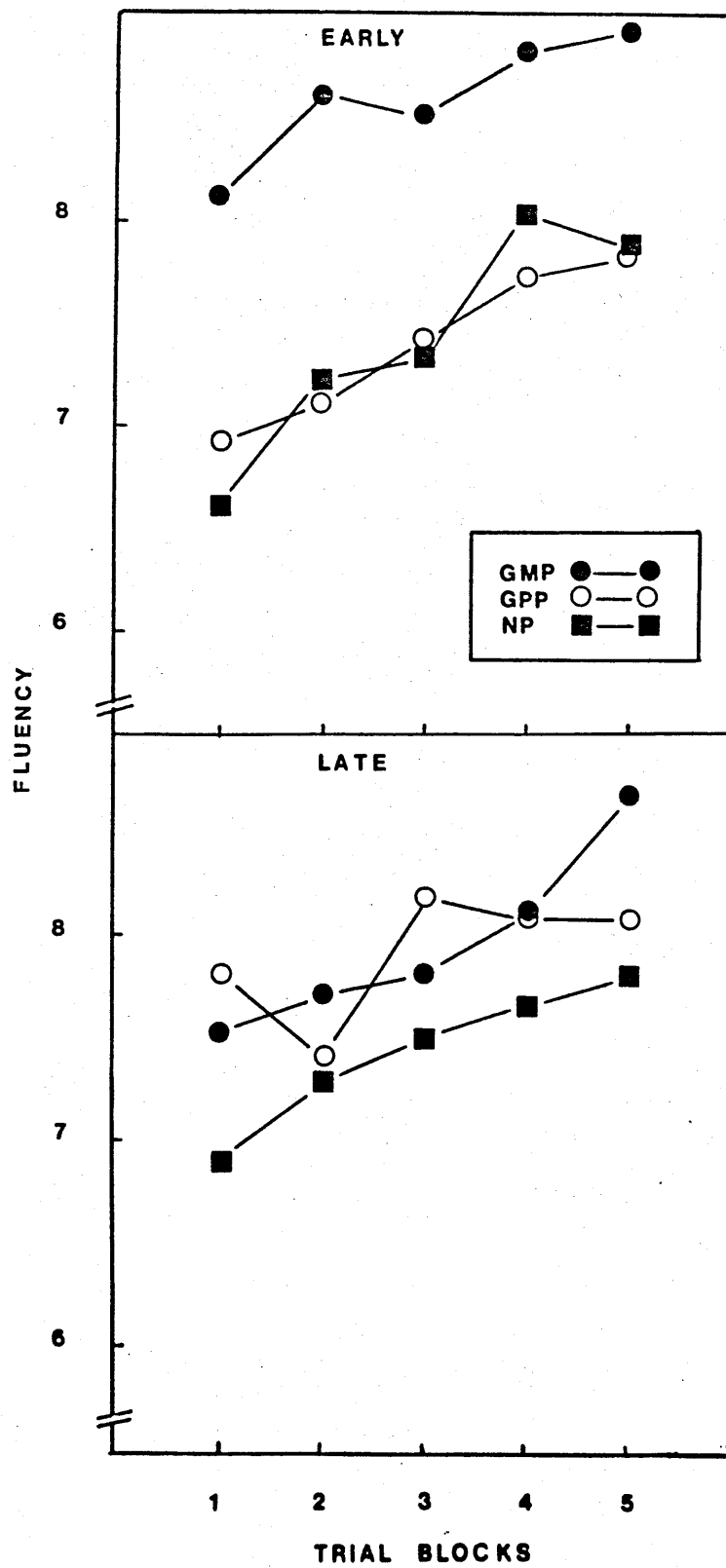


FIGURE 14

FIGURE 15. Mean sequence errors of the various groups during the five test trials. MP, mental practice; PP, physical practice; NP, no-practice.

FIGURE 16. Mean speed of the various groups during the five test trials. MP, mental practice; PP, physical practice; NP, no-practice.

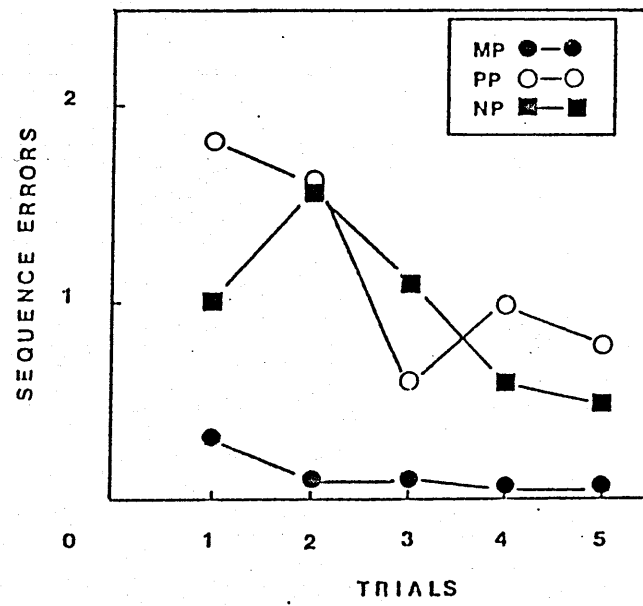


FIGURE 15

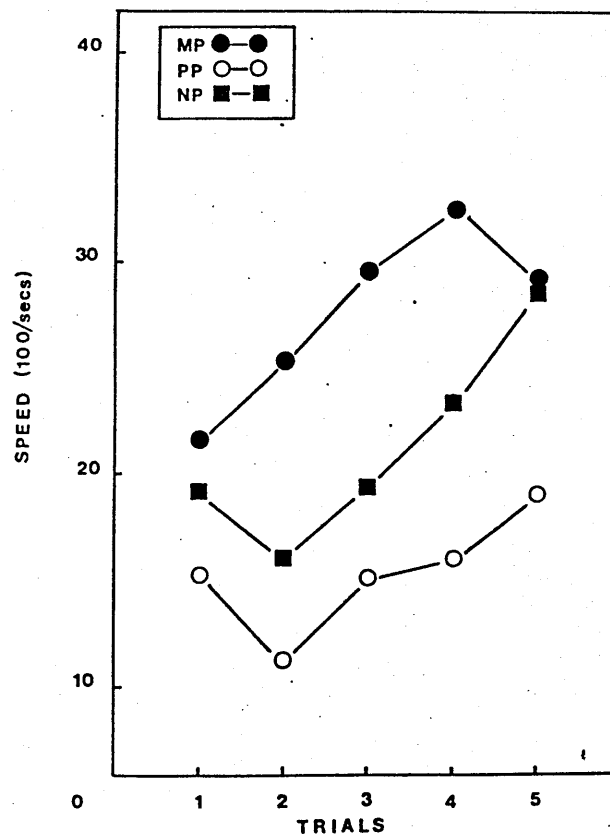


FIGURE 16

Group x Stage interaction just failed to reach the conventional level of significance, $F(2,30) = 2.30$, n.s. Even so, in an attempt to fully characterise the data separate analyses were conducted for the early and late conditions. These revealed a significant effect of groups in the early condition, $F(2,30) = 10.56$, $P < .01$, but not in the late, $F(2,30) = 1.80$, n.s. Individual comparisons showed that Group GMP was significantly faster than Group GPP, which in turn was faster than Group NP, in the early condition, $P < .05$ in all cases. Neither of the between subjects factors entered into significant interaction with Trials, $F(4,120) = 1.59$; $F(8,120) < 1.83$, $P > 0.05$ in both cases.

3.01

Fluency

Figure Fourteen illustrates the quality of performance scores of the various groups in the early and late conditions. The fluency of performance improved over trials, $F(4,120) = 17.07$, $P < .01$, but the effect of groups did not reach significance, $F(2,30) = 3.05$, n.s.

The absence of a significant Group x Stage interaction, $F(2,30) = 1.27$, n.s; failed to confirm the suggestion in Figure Fourteen that the effect of groups was more pronounced in the early condition than in the late condition. The Trials factor did not enter into any significant interaction, $F < 1$ in all cases.

DISCUSSION

The major finding of this study is that when guided mental practice is given before the subject has actual experience of

the task, performance is improved on two evaluative measures; sequence learning and speed of performance, and on the third measure (fluency) the trend is in the same direction (though not significant). On the sequence and speed measures in all cases Group GMP was superior to the control group, Group NP, in the early condition. Moreover in terms of speed, guided mental practice given initially was more effective than comparable physical practice. The advantage conferred by mental practice was evident from the outset of testing and continued throughout the test. This suggests that mental practice does not act by speeding up the rate of learning of the task, but rather, confers some constant positive advantage to the subject. Because the training period was limited, we cannot be certain whether or not this advantage would remain static.

At the present time it is impossible to state explicitly whether changes in speed and fluency of performance are secondary to changes in sequence learning, rather than reflecting an independent effect of mental practice on performance. As I pointed out earlier, Summers (1977) has suggested that planning during skill acquisition is in terms of the redundancy of information. Once the subject has knowledge about the order or sequence of events, they can direct attentional capacity elsewhere. From this point of view it would be reasonable to conclude that the improvement in speed and quality is likely to be secondary to changes in sequence learning. Such an account may well allow us to understand one of the more surprising aspects of the data, namely that the mental practice group was superior to the

physical practice group in terms of the speed measure in the early condition.

It is often assumed that movement generation mechanisms are overseen by some form of executive system which monitors both the formation of an action plan, and the control of performance. Thus it is possible that in Group GPP in the early condition conflicting demands are made on this executive between the formation of the action plan and the handing over of control to effector mechanisms which regulate performance. For the subjects in Group GMP the situation is different, however, as they have the opportunity to structure and organise the action plan, prior to the hand over to, and without interference from effector and performance control mechanisms. This results in more executive capacity being made available to oversee learning of the sequence during the training stage and thus relieves subjects of this task during the test stage. As a result they are then in a position to direct more processing capacity to the performance aspects of the task during test which is reflected in their speed of execution.

Fitts and Posner (1967) characterised the stages of skill learning, the initial stage being the cognitive phase. If mental practice is the manipulation of cognitive aspects of the skill, then it is easy to understand why such practice is beneficial during early learning. Fitts and Posner state, "at this stage behaviour is truly a patchwork of old habits ready to be put together into new patterns". The present findings suggest that not only does guided mental practice facilitate the selection and planning of past movement experience to form

a new motor schema, together with its associated programs, but also that such facilitation is manifest in the quality of the movements themselves.

The present study was not successful in its secondary aim of determining whether the effectiveness of mental practice depended upon the stage of learning at which it was administered. Although none of the measures revealed a significant effect of treatment in the late condition, the statistical analyses did not provide strong grounds for concluding that the effects of these treatments differed in the early and late conditions; only in the case of sequence error was the interaction involving Group and Stage significant.

Some
difference
in stages
non-
significant

Two other problems also arise in the case of the late condition. The first is that at least in the case of sequence error a floor effect may have been operating to constrain the difference between groups; the error rate in the late condition was uniformly low in all groups. Secondly, as guided physical practice failed to improve performance significantly above the level of the no-practice group, it may be argued that at this stage of learning performance measures are insensitive to any treatment procedure.

In conclusion, this study does demonstrate the effectiveness of mental practice in enhancing performance on an interactive gross motor skill, ~~certainly when such practice is given prior to experience on the task.~~ This enhancement can be seen in measures such as learning the sequence of movements, and the speed with which they are performed. The idea that subjects need time to structure the movement plans

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which might involve strategies for success, prior to execution of the movements themselves, is supported by this study.

EXPERIMENT THREE

Introduction

In Experiment Two the mental practice effect was demonstrated using a procedure in which information was provided by external guidance cues in the form of footprints on the runway. Would similar effects emerge without these guidance cues, where mental practice processes were forced to operate on stored information? This next study investigated this question, subjects were required to learn a sequence of movement before adjusting to a change in the sequence. Subjects would then use mental practice to restructure their prior movement experiences in order to generate the modified version of the sequence.

In order to provide subjects with information they were required to learn a particular sequence on the runway and once this was well learned, perform a reversal of that sequence. The mental practice group imagined performing the sequence reversal, before being tested on the task. If mental practice can operate on stored information, we should expect this group to learn the reversal more rapidly than a no-practice control group. In addition, a physical practice group was also included to compare the efficacy of mental and physical practice with this procedure.

METHOD

Subjects

Eighteen female students between 16 and 25 years of age were randomly assigned to one of three groups; mental practice (MP), physical practice (PP) and no-practice (NP).

Apparatus

The runway was a shortened version of that described in Experiment Two. There were nine pairs of squares, and the first and last pairs were used for timing with the remaining squares making up the sequence to be learned.

Procedure

The experiment was divided into three stages; pre-training, training and test.

Pre-Training

During pre-training all subjects were required to traverse the runway stepping only on those squares designated as correct. If the subject stood on an incorrect square that was not part of the sequence to be learned, the feedback tone sounded informing them that the square was not part of the sequence. All subjects performed the task until they reached a criterion of five consecutively correct traverses of the runway. The sequence was; both feet, right foot, left foot, both feet, left foot, neither foot and both feet.

Training

During training subjects in the mental practice group were instructed to imagine themselves performing the task in reverse. Subjects stood on the last pair of squares facing in the opposite direction to that used during the initial pre-training, and they were instructed to imagine themselves performing the task in reverse. Subjects were required to turn their head to the right on the completion of each imaginary traverse of the runway, which allowed the experimenter to count the number of mental practice trials completed. Subjects performed five trials using this procedure. Subjects in the physical practice group performed five actual practice trials without feedback correction, whereas those in the no-practice group performed a simple reading task, for a period of ninety seconds. In neither the mental or physical groups were there any cues indicating the correct sequence.

Test

All groups performed five test trials of the reversed version of the task with feedback correction.

As Experiment Two failed to reveal a significant mental practice effect for the fluency measure performance, the five test trials was analysed only in terms of sequence error and speed measures.

RESULTS

*Refer to Tables G-I
in Appendix*

There were no significant differences in performance of the various groups during pre-training, either in terms of the

number of trials to criterion, $F(2.15) = 2.27$, n.s. or in speed on the last trial of pre-training, $F(2.15) = 2.15$, n.s.

Sequence Learning

Figure Fifteen illustrates sequence errors for the different groups during the five test trials. All groups showed a decrease in errors over trials with the mental practice group showing the lowest scores. An overall analysis revealed significant effects of groups, $F(2.15) = 2.87$, $P < .05$, and effect of trials, $F(4.60) = 2.87$, $P < .05$. The Group x Trial interaction however, was not significant, $F < 1$. Individual comparisons showed that subjects in Group MP committed fewer errors than subjects in Groups NP and PP, $P < .05$.

Speed

Figures Sixteen illustrates the speed of performance of all three groups in the five test trials. In all groups speed improved over trials, $F(4.60) = 4.15$, $P < .01$. There was a significant effect of groups, $F(2.15) = 3.99$, $P < .05$, and individual comparisons showed that Group MP were significantly faster than Group PP, $P < .05$. The Group x Trial interaction was not significant $F < 1$.

DISCUSSION

The pattern of results in Experiment Three are similar to those seen in Experiment Two, in that mental practice did facilitate performance of the sequence reversal, relative to the physical practice and no-practice groups. Although the mental practice group appeared superior to the two other groups on

the speed measure, the statistical analysis revealed a significant difference only between the mental practice group and the physical practice group. Therefore, it is not certain whether mental practice conferred an advantage in terms of speed or that physical practice resulted in an unfavourable climate for performance. The data would suggest that both influences contributed to this effect.

These results indicate that the processes engaged by mental practice can operate on stored information. Furthermore, it is proposed that enforced processing of this information during execution, which is the case in the physical practice group, may lead to interference between the formation of an action plan and the handing over of control to effector mechanisms which oversee performance. It is clear that if subjects have the opportunity to organise the action plan prior to performance, then execution of the movements themselves is improved.

If what the subjects learned in this study was a specific sequence of movements which was under the control of a fixed motor program, then the reversal of the sequence should have made performance worse. But if what is represented in such a program, can be accessed by purely cognitive procedures, in this case mental rehearsal, then performance of the sequence reversal should show minimal deterioration, as was the case with the mental practice group. As mental practice did enhance performance of the reversal, then it is reasonable to assume that sequence information is represented either within the executive control mechanism or as a parameter of the motor program for this sequence of movements. Moreover, these

results demonstrate that subjects who use mental practice can make simple transformations on motor information that is stored in either of these systems.

The idea of making transformations on stored information is not a new one. It is analogous to the transformational rules that are a feature of certain linguistic theories (Williams 1976). Moreover, such rules are possibly one of the features associated with motor programs which are at the heart of schema theory. A motor schema consists of rules and relationships which are capable of generating new actions and are thought to be one method by which individuals can create new motor plans from past movement experiences. The success of mental practice on sequence reversal supports the general idea that movement information is represented at a high level within the CNS in the form of cognitive structures. Given this perspective it would appear that these structures can be manipulated by purely psychological processes which do not necessarily involve concomitant motor activity.

CHAPTER FOUR

IMAGERY
AND MENTAL PRACTICE

	PAGE NUMBER
Introduction	68 - 70
Imagery and Mental Practice	70 - 77
EXPERIMENT FOUR	77 - 82
Method	78 - 79
Results	79 - 80
Discussion	80 - 82

IMAGERY

AND MENTAL PRACTICE

Introduction

The earlier experiments demonstrated that mental practice can enhance the performance of an interactive motor skill; furthermore, individuals are capable of making simple transformations on stored motor information using mental practice to modify a previously experienced sequence of movements. Given these results, we now turn to an analysis of the mechanisms that might underlie the mental practice effect. A starting point is the assumption that mental practice influences the structuring and processing of information prior to execution of a sequence of movements. Seen from this perspective, the problem becomes one of specifying the nature of this information and how it is involved in the movement generation system. One proposal that has received much attention; (Shaw, 1940; Ulrich, 1967; Suinn, 1970; Rawlings and Rawlings, 1974) is that mental practice involves the manipulation of a mental image.

The psychological literature reveals an abundance of attempts to measure imagery and its possible contribution to learning and memory. In 1910 Galton designed one of the first imagery questionnaires with a view to differentiating between different types of imagery; for example visual, kinesthetic and auditory. There has been little success, however, in classifying individuals into specific types of imagers, possibly due to the subjective nature of these

investigations. The search for such innate or acquired habits to think either in pictures or in words, has largely been abandoned as it appears that most individuals can experience the various types of imagery, depending upon circumstances.

Recent investigations into the nature of imagery as related to movement skills are now more objective with the emphasis on spatial and transformation abilities. Research in this area has demonstrated individual differences on this basis. Just and Carpenter (1985) have reported that though differences between high and low spatial ability individuals may be small the resulting differences in performance can be large and very general. They propose that those individuals with high spatial ability are faster in their manipulations and more flexible in their approach on mental rotation tasks such as the Shepard and Metzler rotation task. Using this task Just et al. demonstrated both error rate and reaction time increases for subjects with low spatial abilities.

Current studies of the movement generation system call upon the notion of an image in order to explain various processes. Adams^a (1976) refers to his perceptual trace as a 'motor image' which is strengthened as a result of experience, whereas Gentile (1977) suggests that an image or plan exists to guide execution of the movements to be performed. The type of image referred to here is one associated with closed loop theories of motor control and is not necessarily activated prior to action. In this form the image acts as a model against which performance can be

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compared. By contrast, the image in which we are interested is that which is constructed prior to the execution of any movement. The idea is that individuals pre-select movements prior to performance and this enables them to predict what will happen once they begin to move.

The concept of an anticipatory image (Scott, Kelso and Wallace 1978) has been presented as the basis on which motor commands could be organised; Scott et al state that, "when we pre-select a movement, we *obtain* information that is in terms of our expectations". They further propose that this anticipatory motor image will create within the individual a readiness to receive specific types of information. Moreover, as individuals have prior knowledge of the sensory consequences of their actions the processing of input information is enhanced. Finally, this internal image of the movements to be performed, and the organisation of the motor commands are closely linked. This form of imaging is thought to result in the superior regulation of movements once execution is underway. It may well be that the anticipatory image is constructed on the basis of an individuals' past movement experiences, in which case they may be predisposed to use various methods of imagery construction which would result in individual differences.

Imagery And Mental Practice

Pear (1922) was the first to suggest the possible relationship between imagery and mental practice; he argued that individuals who had never performed a particular sequence of movements were capable of combining them in

imagination to produce a reasonably successful performance when the time for action came. The literature on mental practice reveals some controversy about the type of imagery which might be associated with such practice. One question which has interested researchers in this area is the viewpoint the subject takes when engaged in mental practice. Two possibilities are open to them: first they could imagine themselves, or some primitive human model performing the movements. Second, the practice may be "viewed" from the spectator's viewpoint. Shick (1970) attempted to examine this problem. Using two tasks, the wall volley and the serve, she found that the imagery employed depended on the skill to be achieved. Subjects performing the service task reported that imagery took the form of a spectator's view of the skill, whereas those who imagined executing the wall volley reported that they visualised themselves performing the task. Suinn (1970) has reported that one of the critical factors in his VMBR, (visuo-motor behaviour) practice technique is that self participation is essential for any benefit to accrue from mental practice.

Rawling and Rawlings (1974) examined the relationship between visual imagery and mental practice. Efficiency of imagery was measured by Gordons (1950) test of imagery manipulation and subjects were classified according to this questionnaire as 'controlled' or 'autonomous' imagers. Using the pursuit rotor task, they were given five minutes of physical practice followed by ten minutes rest before five minutes post rest practice. During the rest period

groups of subjects mentally rehearsed the task for three minutes, at the end, middle or beginning of the rest period. Controlled imagers showed less reminiscence than autonomous imagers. Rawlings et al concluded that controlled imagery results in a build up of inhibition, and this is reflected in a decrement in reminiscence. The implication of this study is that mental practice may build up inhibition in the same way as physical practice.

Another aspect of imagery which has been the subject of investigation is its vividness, and the ease with which it can be manipulated. Start and Richardson (1964) used an imagery battery designed by Sutcliffe which purported to measure vividness and modality of imagery. Subjects were rated for imagery on each of seven modalities: visual, auditory, touch, kinesthetic, taste, smell and organic. Using the single leg upstart task all subjects received six daily mental practice periods of five minutes, using an instruction sheet. Then on day seven they were tested on the task. Neither vividness, nor the controllability of imagery related to the performance scores of subjects.

There is evidence from subjective reports that imagery is used during mental practice, but there is very little experimental work to support this claim. It seems plausible that if subjects imagine a sequence of movements then imagery must be involved. The question is what form might such imagery take? The alternative is that subjects use some other strategy to encode the information to be stored. A deceptively simple form of symbolic representation of the sequence for the runway task is a

verbal one. Subjects in Experiment Three were informally questioned following their participation on the runway task, and claimed that during both initial learning, and sequence reversal they did not use a verbal code, although a few said they began by trying a verbal strategy. This was achieved by naming the steps, however, they admitted this method was soon abandoned in favour of either a location code, which was described as picturing where to put their feet, or a kinesthetic code which was characterised by a feeling of what to do at a particular point on the runway. These points were emphasised when subjects discussed strategies for reversing the sequence.

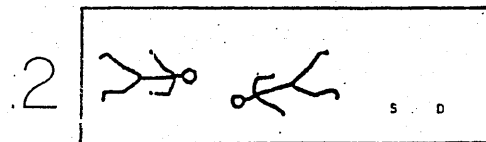
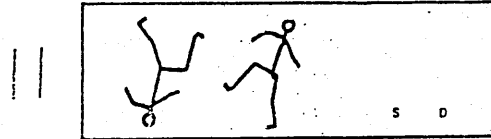
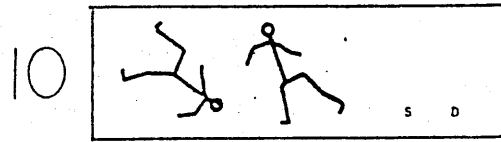
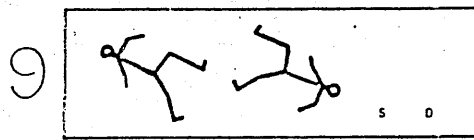
As a result of discussions with these subjects and the association of imagery with mental practice in the literature I decided to investigate whether individual differences in a specific imagery ability was allied with mental practice. Consequently, a decision had to be made about the type of imagery that might be most appropriate to such practice ^{so as to} and design a test that would access this ability. It seemed plausible to assume that the ability to manipulate a visuo-spatial representation would correlate with improvements in performance brought about by mental practice. It has been suggested that those subjects with high spatial abilities are able to construct orientation-free structural representations due to a more complete understanding of the nature of the object (Shepard 1975). If this is so then such processes may include representations of the human body.

From the historical perspective researchers have believed that there exists a system of 'primary' mental abilities or factors which are assumed to be reflected in fundamental psychological processes, one of which is spatial thinking (S factor) Thurstone (1941). This factor is thought to be involved in all tasks that require the manipulation of two or three dimensional objects in the imagination. Fleishman (1950) has argued that the S factor may be a crucial component of imagery during mental practice, particularly during early learning. The S factor has three components:-

- 1) The ability to visualize rigid constructions moved into different positions.
- 2) The ability to visualize a configuration in which there is a displacement of parts.
- 3) A kinesthetic factor.

Thurstones' Flags Test is a measure of spatial thinking, however, the original test used abstract forms, such as squares and circles, and thus constituted a measure of a generalised spatial ability. These abstract two dimensional forms fail to capture some important aspects of human spatial ability as we are able to imagine the movement of an object from one orientation to any other very easily. It may be that the subject's internal representations that are associated with spatial transformations involving the human body are not tapped by rotation tests that consist of abstract forms. Therefore, the effect of mental practice on motor performance may depend upon a more specific ability which would allow subjects to manipulate a symbolic

FIGURE 17 - Items from Flags Test and Stickman Test



Below are more flags. For each of the six flags in the right-hand box, circle the letter S if the flag shows the same side as the single flag in the box at the left; circle the letter O if the flag shows the opposite side of the single flag at the left. This row has been marked.

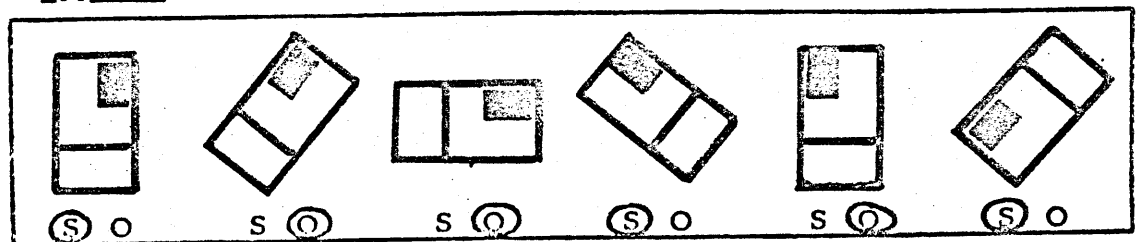
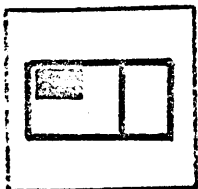


FIGURE 17

representation of the human body. The use of a primitive body image such as a stickman was supported by evidence from Parsons (1987) study. He suggests that imagined spatial transformations of the body probably reflect the dynamic properties of actual movement. Furthermore, Cooper and Shepard (1975) have noted that kinesthetic sensations do accompany spatial transformations that are associated with the human body. Consequently, the Stickman Test was designed in an attempt to capture these specific abilities.

The items in the Flags Test and the Stickman test are similar, except for the fact that the latter employs stick figures, rather than the abstract geometric forms used in the Flags Test. The figure used in the Stickman Test is based on the assumption that movement imagery is a result of prior perceptual experience, and that all adults have through these experiences constructed a form of primitive body image, of which the stick figure is an elementary version. The human body is familiar to all individuals and may well have spatial transformations of its whole or parts associated with it.

The Stickman Test consists of a standard figure and a comparison figure. Subjects were required to state whether or not the comparison figure was a rotation of the standard, in the same plane of the paper. (See Figure Seventeen) They were required to complete as many items as possible in a fixed time period (two minutes),

The validity of the Stickman Test was determined by correlation with Flags Test for sixty-two subjects, 26 males and 36 females aged between 18 and 25 years. However, the

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FIGURE 18, Experiment Four, Number of correct items
completed on Flags and Stickman Tests,

FIGURE 19, Relationship between the number of correct
items completed in the two halves of Stickman Test,

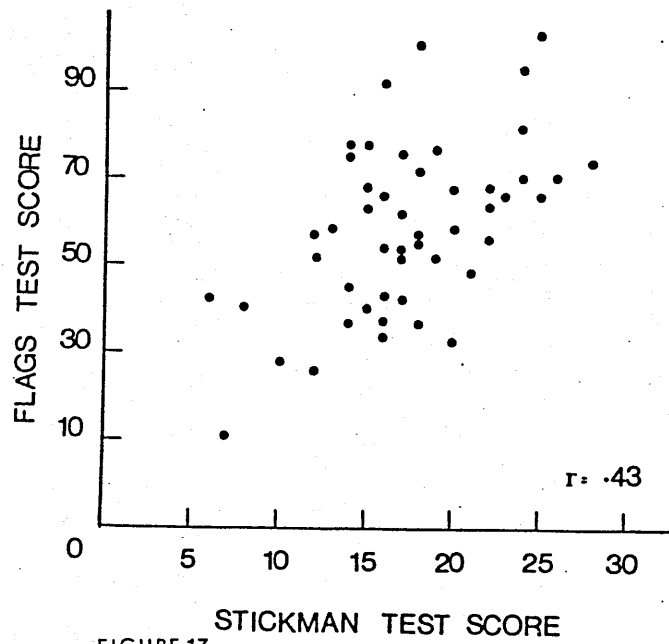


FIGURE 17

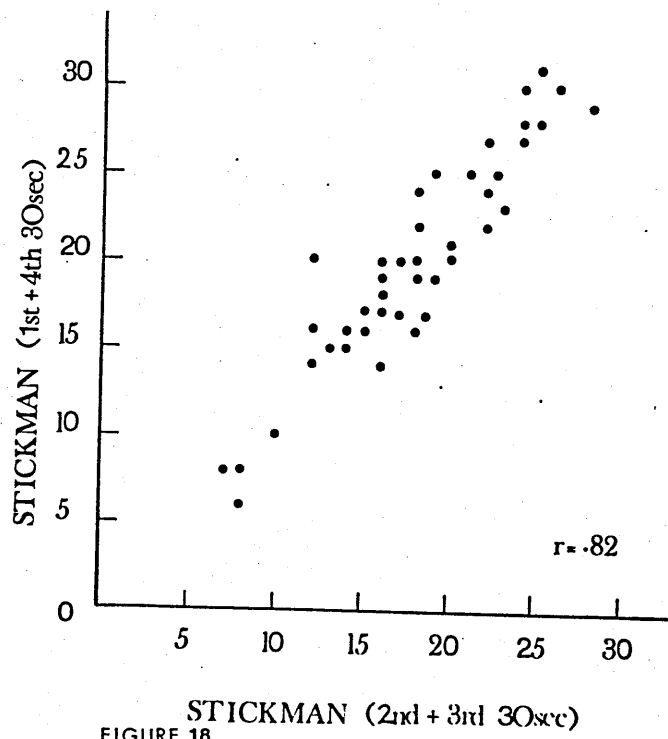


FIGURE 18

correlation coefficient of concurrent validity should not be too high, particularly when using equivalent form tests otherwise the second test could be regarded as a replication of the existent test (Cronbach (1977)). Figure Eighteen illustrates the relationship between the number of correct items completed on Flags and Stickman tests. The Pearson Product-moment correlation between these scores was 0.43, $P < .01$. The expectation is that the Stickman Test will measure another aspect of imagery which is more relevant to movement related tasks.

Reliability was assessed using the split-half method. Figure Nineteen displays the relationship between the number of correct items completed in the two halves of the test. The Pearson Product-moment correlation coefficient was 0.59 which rose to 0.74 after application of the Spearman-Brown formulae. The correlation coefficient for the total-length test was 0.82, $P < .01$.

With the validity and reliability of the Stickman Test assessed as above, it was hoped that it would represent a valid measure of the subject's ability to manipulate a spatial representation relevant to the human body. Shepard and Metzler (1971) had demonstrated that subjects could solve the types of rotational problems found in the Stickman Test, and suggested that subjects were able to accomplish this by rotating a mental image of the target object.

EXPERIMENT FOUR

This study is an attempt to demonstrate that individuals who show a specific imagery ability will produce a better performance on the runway task, following mental practice, when compared to those who do not possess this ability. The experiment was divided into two stages; first, the screening of subjects to find their imagery scores, and second participation on the task following mental practice. After screening subjects were classified into groups on the basis of their scores on the Stickman Test. These were two matched groups of high-scoring subjects and two matched groups of low scoring subjects. All subjects were then tested on the runway using the sequence reversal procedure as detailed in Experiment Three, with one high and one low score group receiving mental practice and the other pair no-practice.

If mental practice depends on employing a form of imagery that is captured by the Stickman Test then we should expect to observe greater differences between the mental practice and no-practice condition when the subjects have a high imagery rating. In addition, this experiment could provide validation of the hypothesis that the Stickman Test measures capacities normally deployed in motor learning. Given this supposition it could be expected that subjects with high imagery scores would learn the initial task more effectively than those with low scores.

METHOD

Subjects And Screening

Seventy-seven female subjects, aged between 18-25 years were given the Stickman Test, and required to complete as many items as possible in a two minute period. The raw scores from all subjects were used to allocate them to two high-score and two low-score groups of six subjects each. Six matched pairs of subjects were selected from the low scoring subjects and one member of each pair was assigned to a mental practice group (Group MP-L) and the other to a no-practice group (NP-L). The same procedure was followed for high scoring subjects to generate another mental practice group (Group MP-H) and a no-practice group (Group NP-H). The mean Stickman Test scores were: MP-L, 12.3; NP-L, 11.0; MP-H, 31.0; NP-H, 30.5.

Apparatus

The shortened version of the runway was employed and the procedure was the same as that used in Experiment Three. Subjects were required to learn the sequence using a trial and error method and received feedback correction until they reached a criterion of three consecutively correct traverses of the runway. Following this the mental practice subjects performed five mental practice trials using the reversed sequence and the no-practice groups performed a simple reading task. Finally, all subjects performed five test trials using the reversed sequence and receiving feedback correction.

RESULTS

An analysis of the number of trials to criterion during initial training revealed that subjects with high imagery scores learned the task faster than those with low imagery scores, $t(11) = 2.31$, $P < 0.05$. The mean trials to criterion for the high scoring subjects was 9.5 and for low scoring subjects was 15.3.

Performance during the five test trials with the reversed sequence was measured in terms of the number of errors on each trial, (sequence learning) and the time taken to complete one traverse of the runway, (speed). These scores were analysed by a three-way mixed ANOVA with type of training (mental practice vs no-practice) and imagery level as between-subject factors, and the number of test trials as a within-subject factor.

*Refer to Tables J-K
in Appendix*

Sequence

Figure Twenty illustrates the mean number of errors on each test trial. Subjects in the mental practice condition made on average less than one error on the first trial, whereas subjects in the no-practice condition committed substantially more errors. With extended testing this difference disappeared due to the improvement in the no-practice condition. There was a significant effect of training condition, $F(1,20) = 4.41$, $P < 0.05$, and a significant Training x Trials interaction, $F(4,80) = 3.03$, $P < 0.05$.

Error scores of the subjects was unaffected by their imagery rating: there was no significant effect of imagery

FIGURE 20. Mean number of sequence errors during the test trials. MP-H, mental practice/high score; MP-L, mental practice/low score; NP-H, no-practice/high score; NP-L, no-practice/low score.

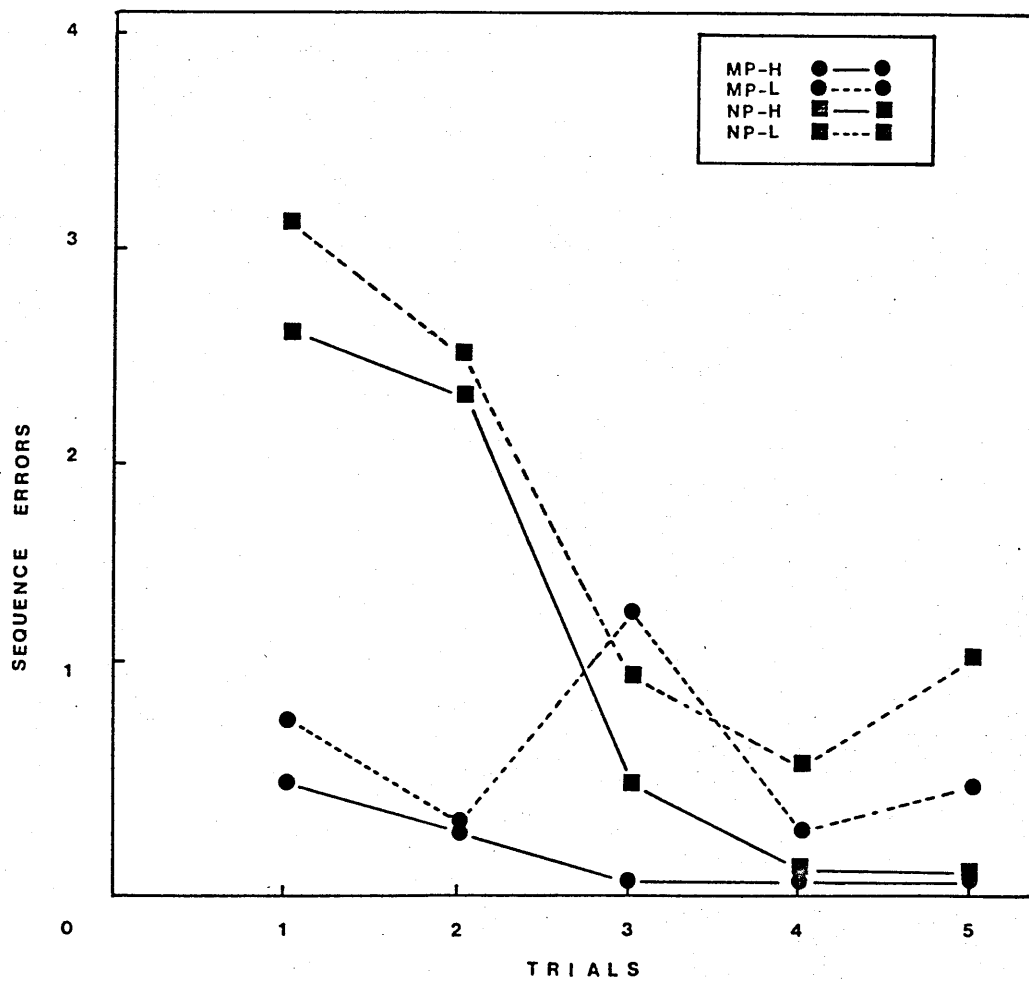
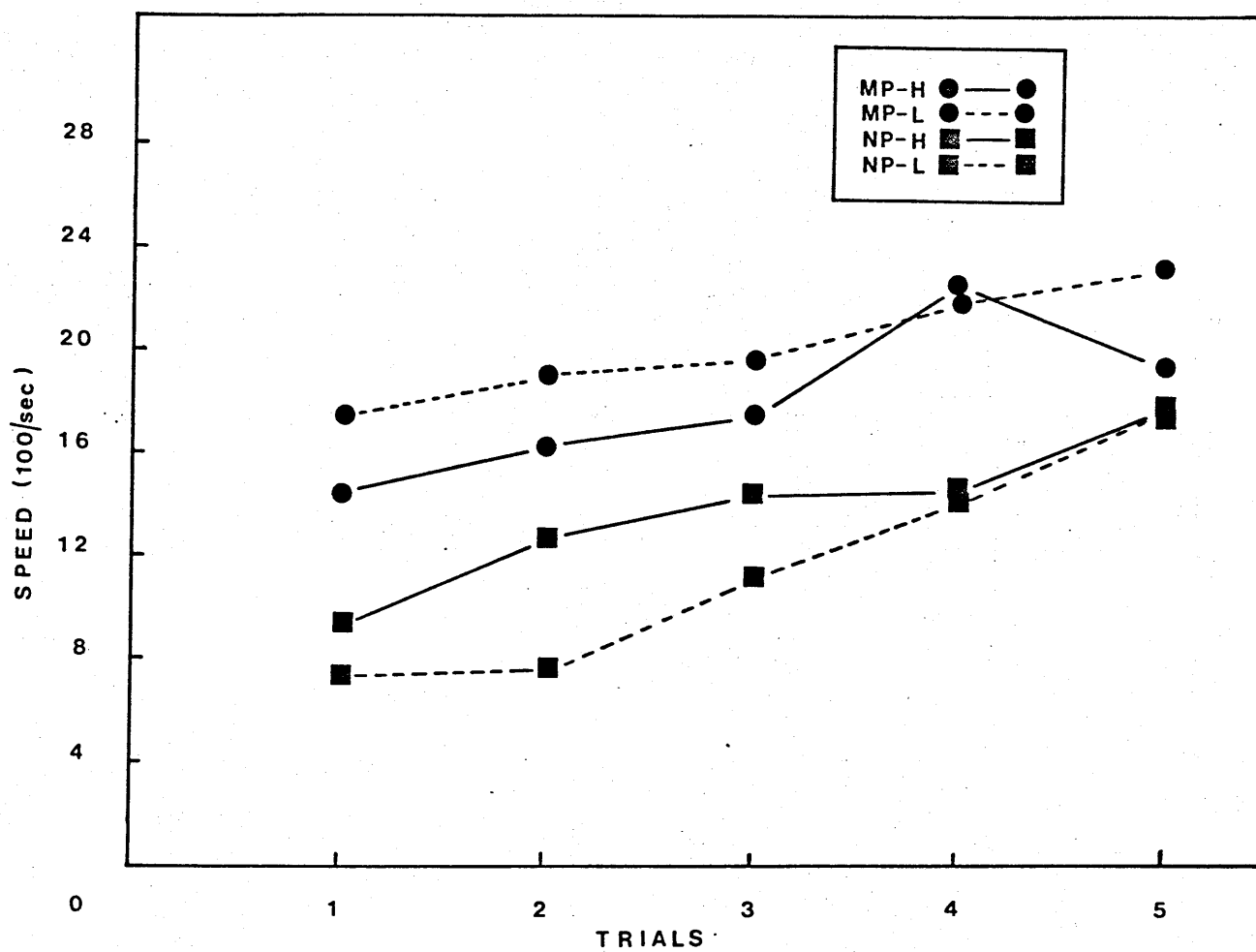


FIGURE 21. Mean speed of the various groups during the test trials. MP-H, mental practice/high score; MP-L, mental practice low score; NP-H, no-practice/high score; NP-L, no-practice low score.



level, $F(1,20) = 1.14$, n.s., and no significant interactions involving this factor, $F < 1$ in all cases.

Speed

Figure Twenty-one displays the speed of performance during the test trials. From the outset of testing, subjects in the mental practice condition performed faster than those in the no-practice condition and this difference was sustained across all the test trials during which there was a progressive increase in speed. There was a significant main effect of training condition, $F(1,20) = 5.00$, $P < .05$, and trials $F(4,80) = 16.43$, $P < 0.05$, although there was no significant interaction between these two factors $F < 1$.

There was no evidence that subjects with high imagery scores benefited more from mental practice in terms of speed of performance than those with low scores. In fact Figure Nineteen shows that the low scorers tended to show the greater increment in speed relative to the no-practice control condition following mental practice, at least during initial learning. This difference was not significant, however; the main effect of imagery and all interaction involving this factor failed to reach significance.

DISCUSSION

This study replicated the findings of Experiment Three, in that mental practice could enhance performance of a task based on stored information. Contrary to expectations, however, there was no evidence that the beneficial effects

of mental practice depended upon the subjects capacity to manipulate visuo-spatial information, at least as measured by the Stickman Test.

In the introduction to this experiment it was suggested that this study would reveal the ability of the Stickman Test to measure^a capacity that might be involved in learning this type of task. Results show that the Stickman Test did indeed discriminate between groups during initial learning on this task, which is supported by the difference in the number of trials to criterion between the high and lower imagers. It would appear from this finding that the Stickman test does capture differences in imagery abilities that are part of the processes that accompany the early stage of learning.

The reasons why variations in imagery ability failed to affect the extent to which subjects might benefit from mental practice are not clear, however, certain suggestions can be proposed. It is possible that Stickman does not measure the particular imagery ability that accompanies mental practice. Subjects may use a form of imagery which is not captured by the test. It should be noted, however, that a simple verbal form of encoding of the sequence for this task is a strategy which is open to the subjects, but reports from participants, as described earlier, would suggest this to be unlikely. Moreover, for many tasks such as dancing, pole vaulting and swimming, verbal coding would be an ineffective, if not impossible, strategy for organising such movements. The same seems to apply to the runway task. Work by later researchers such as Parsons (1987) has

provided justification for the approach and ideas that were encompassed by the Stickman Test. Parsons⁵ states, "temporal and kinematic properties of imagined spatial transformations are strongly affected by the properties of the imagined object".

Overall, the present experiment indicates that imagery manipulation as measured by the Stickman Test does play a role during early learning, when the subject is attempting to grasp the overall framework of the task, but there is no evidence that it is associated with mental practice that occurred once the subject had prior knowledge of the task. As far as mental practice is concerned it appears we must look elsewhere to understand how it might operate within the movement generation system once the individual has prior experience with the task.

CHAPTER FIVE

CONCLUSIONS

	PAGE NUMBER
Introduction	83 - 83
MENTAL PRACTICE AND THE SYMBOLIC LEARNING HYPOTHESIS	83 - 86
MENTAL PRACTICE AND MOTOR PROGRAMS	86 - 86
SIMPLE ACQUISITION OF THE RUNWAY TASK	86 - 90
The Cognitive Stage	87 - 88
The Associative Stage	88 - 90
SEQUENCE REVERSAL ON THE RUNWAY TASK	90 - 92
FUTURE DIRECTIONS AND APPLICATIONS	92 - 93

CONCLUSIONS

Introduction

This final chapter reviews the experimental results in terms of the two ideas discussed in Chapter One, 'Motor Control And The Aims Of The Present Studies'. The first was that mental practice works by manipulating the sequential or symbolic component of a motor skill, thereby bringing about enhanced performance. The second was that such practice may be the process by which individuals prepare the motor programs prior to execution. It was also pointed out that there may be some difficulty in separating these two proposals. The implications of the present results will be considered for both proposals, although it is recognised that these experiments do not allow us to discriminate clearly between the two accounts.

MENTAL PRACTICE AND THE SYMBOLIC LEARNING HYPOTHESIS

In the introduction to this thesis it was suggested that mental practice operates by organising the cognitive components, or sequencing of a task. Motor skills can be divided into two basic components, the cognitive or symbolic component and the motor acts themselves. The idea that mental practice facilitates acquisition of the cognitive aspect of a task is not a new one (Morrisett, 1967; Smyth, 1975). The cognitive element of a motor skill is thought to be the organisation and structuring of rules which govern execution of the movements. In the case of the runway task this is interpreted as learning the correct sequence, which is

essential before the appropriate movements can be made. Furthermore, the complexity of this sequential information can be manipulated as was shown in Experiment One and by using this procedure the cognitive demands of the runway task can be altered. Results demonstrated that this task did reflect such differences in demand.

Subjects who are presented with the sequential information, prior to execution, and given the opportunity to engage in mental practice of that information show superior performance on the runway task, relative to a no-practice control group. Moreover, such practice is almost as effective as actually performing the task, which was demonstrated in Experiment Two. Once the subject has stored information relating to the sequential aspect of the task, can it then be manipulated so as to change the sequence of movements? Experiment Three examined this question. A sequence of movement was learned and then the series was reversed, forcing the subject to make changes in the cognitive information previously stored. The results demonstrated that subjects who engage in mental practice can accomplish such manipulations effectively, relative to both a physical and no-practice condition.

The symbolic learning hypothesis states that mental practice allows the subject to structure and organise the constituent movements of a task (Morrisett (1967)). Furthermore, learning will only be enhanced to the extent that such factors are involved in the task. Jones (1963) and Summers (1977) have both suggested that the symbolic aspect of an interactive task is sequential in nature and the fact that I have been able to observe a large and reliable mental practice

effect in the present studies may well reflect the sequential nature of these tasks.

Jones (1963) went on to suggest that the symbolic component of a motor task may be in the form of a 'kinesthetic image', and that mental practice facilitates the formation of such an image. Other researchers have also stressed the association of imagery and mental practice as an aid to the formation of a motor plan; Pear (1922), Start and Richardson (1964), Rawlings and Rawlings (1974). Hence imagery has become one of the most popular candidates for explaining mental practice processes. The aim of the final study in this thesis was to reveal individual differences in imagery abilities and their possible relationship to the subsequent benefits to be gained from mental practice.

A new test of imagery was designed, (the Stickman Test) in the hope that it would measure individual differences in movement related spatial imagery. In Experiment Four those subjects who were rated as high imagers on the Stickman Test did show a faster rate of initial acquisition on the runway task which supported the proposal that this early stage of learning may involve imagery in terms of spatial factors. However, this factor did not appear to affect the benefit gained from mental practice using the sequence reversal procedure. Such a result, however, does at least eliminate one source for the mental practice effect, in that imagery as measured by the Stickman Test is not involved in the processes engaged by mental practice.

Overall the symbolic learning hypothesis, if interpreted as the sequential and structural organisation that is involved in

learning a novel motor skill receives support from this work. The association of this hypothesis with imagery, however, was not established. Some form of imagery may indeed be used by those who engage in mental practice but the exact nature of this imagery has yet to be revealed.

MENTAL PRACTICE AND MOTOR PROGRAMS

The second proposal put forward in the introduction was that mental practice gave subjects the opportunity to prepare the motor programs appropriate to the task. I shall approach the problem of developing an interpretation of this proposal by providing a theoretical account of the pattern of experimental results. By its very nature, any such account will be post hoc as the experiments were not designed to differentiate between the various theories of mental practice. I shall approach the problem of developing an interpretation of the results by first considering one possible explanation of the simple acquisition of the runway task and follow this by discussing the points at which mental practice could act.

SIMPLE ACQUISITION OF THE RUNWAY TASK

In order to analyse the task I shall use a simplified version, consisting of two movements, such as a transition from two feet to the left foot, and from the left foot to the right foot. Furthermore, I shall assume that the subject comes to the task with pre-formed motor programs, p1 and p2, that will control these movements. This is not an unreasonable assumption as such actions are likely to be highly practised. Within this framework I shall follow Fitts and Posner (1967)

in assuming that learning under the trial-and-error, or no-practice condition consists of at least two stages.

The Cognitive Stage

The subject must first grasp the overall framework of the task, which in this case means they must learn a particular sequence of movements and then execute them with accuracy and control. During the pre-activity phase it is proposed that the subject is constructing an overall plan which is needed to attempt the task. Within the context of this task the subject is presented with the runway and stands in front of the two start squares, where they receive instructions about how the task is to be achieved. Initial conditions and past movement experiences will contribute to the subjects' construction of their overall plan of action and once this has occurred, they can attempt the task.

When the subjects stand on the start squares their first problem is to learn the sequence of movements. Having accomplished this, they are in a position to execute the sequence without error. However, the subjects' performance would not be fluid and fast, as at this stage the movement generation system is involved in a number of transfers of control between an executive, which has access to the memory for the sequence and effector mechanisms (which execute the motor programs). Initially, the executive retrieves information about the first movement required, and on the basis of this instructs the effector mechanisms to execute the appropriate motor program p1. Having run p1, control returns to the executive for information for the next step in the

sequence. Once knowledge is accessed about the next movement the second program, p2, can be initiated. Thus the second movement, a transition from a hop on the left foot to a hop on the right foot is achieved. This accomplishes the final step in this illustrative sequence, and there is no reason to suppose that for longer sequences these procedures could not be repeated.

This model describes the type of processes that might constitute the initial phase of performance on the runway task. The resulting performance at this stage would be full of 'stops and starts' and be a very inefficient way of executing a series of movements along the runway. If the subject is to progress to a more skilled performance changes must occur in control systems to make execution more effective. In the introduction to this thesis the 'Gearshift' theory of control was discussed and it might be reasonable to assume that such a procedure might now come into operation.

The Associative Stage

Once the subjects have mastered the cognitive stage, they are now experiencing reliable execution of p1 followed by p2 in sequence. This, I shall assume, is sufficient to lead to the construction of a new motor program P3 which, when called, will execute the two steps without a return of control and reference to the cognitive representation of the sequence.

The process, which I have outlined here, is in line with current thinking about the type of systems involved in motor control, in that they are by nature constructive. The question that we must now address, is where does mental practice have

its effect and why might such practice enhance performance on the runway task?

An obvious point at which mental practice could act is during the initial cognitive stage of learning. The guided mental practice condition in Experiment Two enabled the subjects to learn the sequence, so that from the outset they could execute p1 followed by p2 in order, thus allowing them to start constructing P3 on the very first trial of actual performance. There are, however, problems with this simple interpretation. First, one might expect guided physical practice to confer an even greater benefit during initial acquisition than guided mental practice. Not only did the guided physical practice group have the same opportunity to learn the sequence they were also in a position to start constructing P3, by the sequential performance of p1 and p2 before the initial trial of acquisition. And yet guided mental practice was at least as good as guided physical practice in terms of error, in fact, significantly better in terms of speed, possibly the measure most likely to reflect the construction of a higher-order program (P3).

Secondly, it is not clear from this analysis why mental practice should be better than physical practice on the reversal of the sequence. A final problem with the idea that mental practice simply benefits the learning of the sequence concerns the fact that the advantage conferred by this form of practice was not affected by individual differences in imagery. On intuitive grounds one would expect imagery to make the greatest contribution to the sequence learning and there was

evidence that initial acquisition is affected by the subjects' performance on the Stickman Test.

A more radical interpretation of mental practice is that not only might it aid sequence learning but also could allow the subject to start constructing the high-order program P3. Thus this interpretation would argue that simply mentally executing p1 and p2 in sequence is sufficient for the generation of P3 (Schmidt 1982). Even this theory leaves us with the problem of explaining why mental practice is better than physical practice in bringing about sequence reversal.

SEQUENCE REVERSAL ON THE RUNWAY TASK

In attempting to explain the reversal performance I shall presuppose that the subjects have, to a large extent, forgotten the cognitive representation of the sequence and their performance is dependent upon executing the higher order program P3. When faced with the reversal task the subjects have to return to the cognitive stage and construct a representation of the reversed sequence. One way they could do this is by mentally running P3 until they get to the last step and remembering this as the first step in the new sequence. This procedure could then be repeated successively in order to determine the remaining steps of the new series. Once the reversed sequence has been constructed and remembered subjects could execute the task by the switching of control between the executive and effector mechanisms, which in turn leads to the construction of a higher order program.

Given this analysis of the reversal processes the main difference between mental and physical practice is that the

physical practice subjects have an explicit marker of their current location in the reconstructed sequence. This is, of course, their present location on the runway. Thus they are always in a position to determine the next step in the reversed sequence by simply running P3 mentally, until they arrive at their current location. This means that in order to perform the reversed sequence it is not necessary for them to remember the series of steps they have already executed. In fact, with physical practice the subjects could, in theory perform the reversed sequence without ever learning it, simply by repetitive running of P3 mentally until they achieved their current location.

By contrast, the mental practice subjects are forced to remember each element of the reversed sequence that they have already constructed in order to determine where to stop the mental execution of P3, which specifies the next step to be added to the construction of the reversed series. Of necessity mental practice requires the subject to store information about the new sequence and this allows them to enter the cognitive phase of learning more rapidly than the physical practice subjects.

According to this analysis, it is the task demands of mental practice that confers its advantage in reversal learning, rather than any intrinsic benefit it has over physical practice on motor learning in general.

The theory of mental practice described illustrates how it might be involved within the movement generation system. Such practice is capable of enhancing performance during the initial stage of learning and continues to benefit the learner by

facilitating the combination of movement elements within a sequence, which results in a smooth and fluent performance. The theory presented also proposes an account of how mental practice may intervene during transformations on stored movement information in order to generate a novel series of movements and influence high level organisational processes which are involved in the sequencing of movements. Mental practice appears to be capable of manipulating and structuring this information so making the government of movements more flexible. Overall, mental practice can enhance learning due to its involvement in the processes which structure the movements within a sequence, once that sequence is known. It is the contribution of mental practice at this point which results in a more skilled performance of the task.

FUTURE DIRECTIONS AND APPLICATIONS

The main thrust of future research should be directed towards discovering the range of tasks and the individual characteristics for which mental practice is most effective. The task examined in the present studies was representative of a particular class of skills, that is those which have a distinct sequential component together with the motor acts themselves. Mental practice may positively effect the performance of other types of skills, but this question has yet to be investigated. Much recent research has been directed toward distinguishing the nature of individual differences in imagined spatial transformations, with particular reference to the human body. The ideas involved in such work are closely

associated with the individual's activity during mental practice.

The current studies of imagined spatial transformations are centred around the notion that the ability to manipulate images is more object specific than had been thought previously. Work such as this may lead to an understanding of the type of representations we possess about our bodies and our actions. Within this context, it may be possible to advise individuals in a more appropriate manner about the requirements of successful mental practice prior to the acquisition of a novel task or skill.

At the present time mental practice does have some practical applications. Possibly the largest users of such practice techniques are sports coaches and physical educators. Indeed for many American and Eastern Block countries mental practice is an essential part of their training procedures. In industry too, mental practice may have a role to play in the future as a training procedure for jobs, especially those where machine operatives must learn complex sequences of movements. Finally, within the clinical situation such practice might prove to be a useful therapeutic tool, specifically in the area of physiotherapy (Richardson 1964). For people such as dancers and athletes, who through injury are forced into inactivity, and other individuals who may suffer temporary paralysis, such as stroke patients, mental practice could provide them with a means for facilitating the recovery of movement.

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APPENDIX

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FIGURES

		PAGE NUMBER
FIGURE 1	Hierarchy of a badminton smash,	14
FIGURE 2	The ball-throw task situation,	31
FIGURE 3	Dickinson 1978 - Overall performance of the various groups,	32
FIGURE 4	Dickinson 1978 - Bins correct for all the various groups,	32
FIGURE 5	Two examples of Johnson's task,	45
FIGURE 6	Experiment One, The two sequences used,	47
FIGURE 7	Experiment One, Mean number of error for all the various groups,	49
FIGURE 8	Experiment One, Mean number of errors for all groups as a function of the serial position curve,	50
FIGURE 9	Experiment One, Mean speed of the various groups,	50
FIGURE 10	Experiment One, Mean performance ratings of the various groups,	50
FIGURE 11	The Runway (with guidance cues)	54
FIGURE 12	Experiment Two, Mean sequence errors of the various groups,	56
FIGURE 13	Experiment Two, Mean speed of the various groups,	57
FIGURE 14	Experiment Two, Fluency scores for all the various groups,	58
FIGURE 15	Experiment Three, Mean sequence errors for all the various groups,	65
FIGURE 16	Experiment Three, Mean speed of all the various groups,	65
FIGURE 17	Items from Flags Test and Stickman Test,	75
FIGURE 18	Experiment Four, Number of correct items completed on Flags and Stickman Tests,	76

FIGURE 19	Experiment Four, Relationship between the number of correct items completed in the two halves of Stickman Test,	76
FIGURE 20	Experiment Five, Mean number of errors for all the various groups,	79
FIGURE 21	Experiment Five, Mean speed of all the various groups,	80

TABLE A
EXPERIMENT ONE

<u>SEQUENCE</u> <u>FACTOR</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
<u>Between subjects</u>				
Task Difficulty (D)	231,41	1	231,42	20,80
Inspection Time (I)	136,02	1	136,02	12,21
D x I	45,71	1	45,71	4,11
Error	177,94	16	11,12	-
<u>Within Subjects</u>				
Trials (T)	206,26	6	34,38	6,87
D x T	16,17	6	2,69	0,53
I x T	13,08	6	2,18	0,43
Dx I x T	13,08	6	2,18	0,43
Error	480,05	96	5,00	-

Tables A - K

It would be helpful to
indicate with an asterisk
which F ratios are significant

TABLE B
EXPERIMENT ONE

SPEED

FACTOR	ss	df	ms	F
<u>Between subjects</u>				
Task Difficulty (D)	767,98	1	767,98	12,14
Inspection Time (I)	25,62	1	25,62	0,40
D x I	90,72	1	90,72	1,43
Error	1011,42	6	63,21	-
<u>Within Subjects</u>				
Trials (T)	109,61	6	18,27	8,47
D x T	31,68	6	5,28	2,45
I x T	21,94	6	3,65	1,69
D x I x T	11,12	6	1,85	0,86
Error	206,86	96	3,17	-

TABLE C

EXPERIMENT ONE

FLUENCY FACTOR	SS	df	MS	F
<u>Between subjects</u>				
Task Difficulty (D)	52.82	1	52.82	13.50
Inspect Time (I)	5.6	1	5.6	1.43
D x I	10.31	1	10.31	2.63
Error	62.57	16	3.91	
<u>Within subjects</u>				
Trials (T)	18.48	6	3.08	10.33
D x T	0.37	6	0.06	0.20
I x T	1.0	6	0.16	0.55
D x I x T	2.08	6	0.34	1.16
Error	28.62	96	0.29	-

TABLE D

EXPERIMENT TWO

SEQUENCE - Overall Analysis

FACTOR	ss	df	ms	F
--------	----	----	----	---

Between subjects

Stage (S)	64,56	1	64,56	7,97
Group(G)	65,62	2	32,81	4,05
S x G	49,76	2	24,88	3,07
Error	242,99	30	8,10	-

Within Subjects

Trials (T)	71,08	4	17,77	15,95
S x T	13,63	4	3,40	3,66
G x T	28,37	8	3,54	3,18
S x G x T	20,66	8	2,58	2,31
Error	133,66	120	1,11	-

Separate Analysis - Sequence

Early Condition

Group (G)	109,24	2	54,62	6,74
Error (Overall)	242,99	30	8,10	-

Late Condition

Group (G)	5,96	2	2,98	0,37
Error (Overall)	242,99	30	8,10	-

TABLE E

EXPERIMENT TWO

SPEED - Overall Analysis

FACTOR	SS	df	MS	F
--------	----	----	----	---

Between subjects

Stage	2,09	1	2,09	0,03
Group (6)	1039,49	2	5,19	8,10
S x G	386,91	2	193,45	3,01
Error	1923,46	30	64,11	-

Within Subjects

Trials	594,35	4	148,58	29,17
S x T	32,53	4	8,13	1,59
G x T	74,28	8	8,13	1,82
S x G x T	45,24	8	5,65	1,11
Error	611,23	120	5,09	-

Seperate Analysis Speed

Early Condition

FACTOR	SS	df	MS	F
--------	----	----	----	---

Group (6)	1352,06	2	676,03	10,56
Error (Overall)	1923,46	30	64,11	-

Late Condition

Group (6)	230,15	2	115,07	1,80
Error (Overall)	1923,46	30	64,11	-

TABLE F
EXPERIMENT TWO

<u>FLUENCY</u> <u>FACTOR</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
<u>Between subjects</u>				
Stage (S)	0,00	1	0,00	0,0
Group(6)	23,82	2	11,91	3,05
S x 6	9,96	2	4,98	1,27
Error	117,16	30	3,90	-
<u>Within Subjects</u>				
Trials (T)	20,63	4	5,15	17,07
S x T	0,81	4	0,20	0,67
6 x T	2,48	8	0,31	0,67
S x 6 x T	1,57	8	0,19	0,65
Error	36,26	120	0,30	-

TABLE G
EXPERIMENT THREE

<u>TRIALS TO CRITERION</u>				
<u>FACTOR</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Groups(6)	169,00	2	84,50	2,27
Error	557,00	15	37,13	-
<u>Speed Last Trial Prior To Treatment</u>				
<u>FACTOR</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
Groups (6)	267,00	2	133,54	2,49
Error	803,73	15	53,58	-

TABLE H
EXPERIMENT THREE

<u>SEQUENCE</u>				
<u>FACTOR</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
<u>Between subjects</u>				
Groups (6)	18,28	2	9,64	4,71
Error	30,66	15	2,04	-
<u>Within Subjects</u>				
Trials (T)	7,22	4	1,80	2,87
6 x T	4,71	8	0,58	0,93

TABLE I
EXPERIMENT THREE

SPEED FACTOR	SS	df	MS	F
<u>Between subjects</u>				
Groups (G)	2225.62	2	1112.81	3.99
Error	4182.74	15	278.85	5.25
<u>Within Subjects</u>				
Trials (T)	880.38	4	220.09	4.15
G x T	321.22	8	40.15	0.75
Error	3182.46	60	53.04	-

TABLE J

EXPERIMENT FOUR

<u>SEQUENCE</u> <u>FACTOR</u>	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
<u>Between Subjects</u>				
Training (T)	31.00	1	31.00	4.41
Imagery (I)	8.00	1	8.00	1.14
TR x I	140.50	20	7.02	-
<u>Within Subjects</u>				
Trials	38.86	4	9.71	4.39
T x TR	26.86	4	6.71	3.03
T x I	2.53	4	8.63	0.28
T x I TR	1.53	4	0.38	0.17
Error	177.00	80	2.21	-

TABLE K
EXPERIMENT FOUR

<u>Speed</u> <u>FACTOR</u>	<u>ss</u>	<u>df</u>	<u>ms</u>	<u>F</u>
<u>Between Subjects</u>				
Training (TR)	1402,15	1	1402,18	5,00
Imagery (I)	4,73	1	4,73	0,01
TR x I	109,54	1	109,54	0,39
Error	5606,15	20	280,30	-
<u>Within Subjects</u>				
Trials (T)	99,41	4	249,60	16,43
T x TR	40,93	4	10,23	0,67
T x TR x I	103,31	4	25,82	1,70
Error	1214,73	80	15,18	-

TABLE K

Repeat

EXPERIMENT FOUR

<u>Speed</u> FACTOR	SS	df	MS	F
<u>Between Subjects</u>				
Training (TR)	1402,15	1	1402,18	5,00
Imagery (I)	4,73	1	4,73	0,01
TR x I	109,54	1	109,54	0,39
Error	5606,15	20	280,30	-
<u>Within Subjects</u>				
Trials (T)	99,41	4	249,60	16,43
T x TR	40,93	4	10,23	0,67
T x TR x I	103,31	4	25,82	1,70
Error	1214,73	80	15,18	-

TABLE ONE

DESIGN OF EXPERIMENT TWO

GROUP	PRE-TRAINING (5 Trials)	TRAINING (10 Trials)	TEST (15 Trials)
GMP/L	PP	GMP	PP
GPP/L	PP	GPP	PP
NP/L	PP	NP	PP
GMP	-	GMP	PP
GPP	-	GPP	PP
NP	-	NP	PP

PP = Physical Practice; GPP = Guided Physical Practice;
GMP = Guided Mental Practice; NP = No Practice,